The future of California's climate from a global perspective

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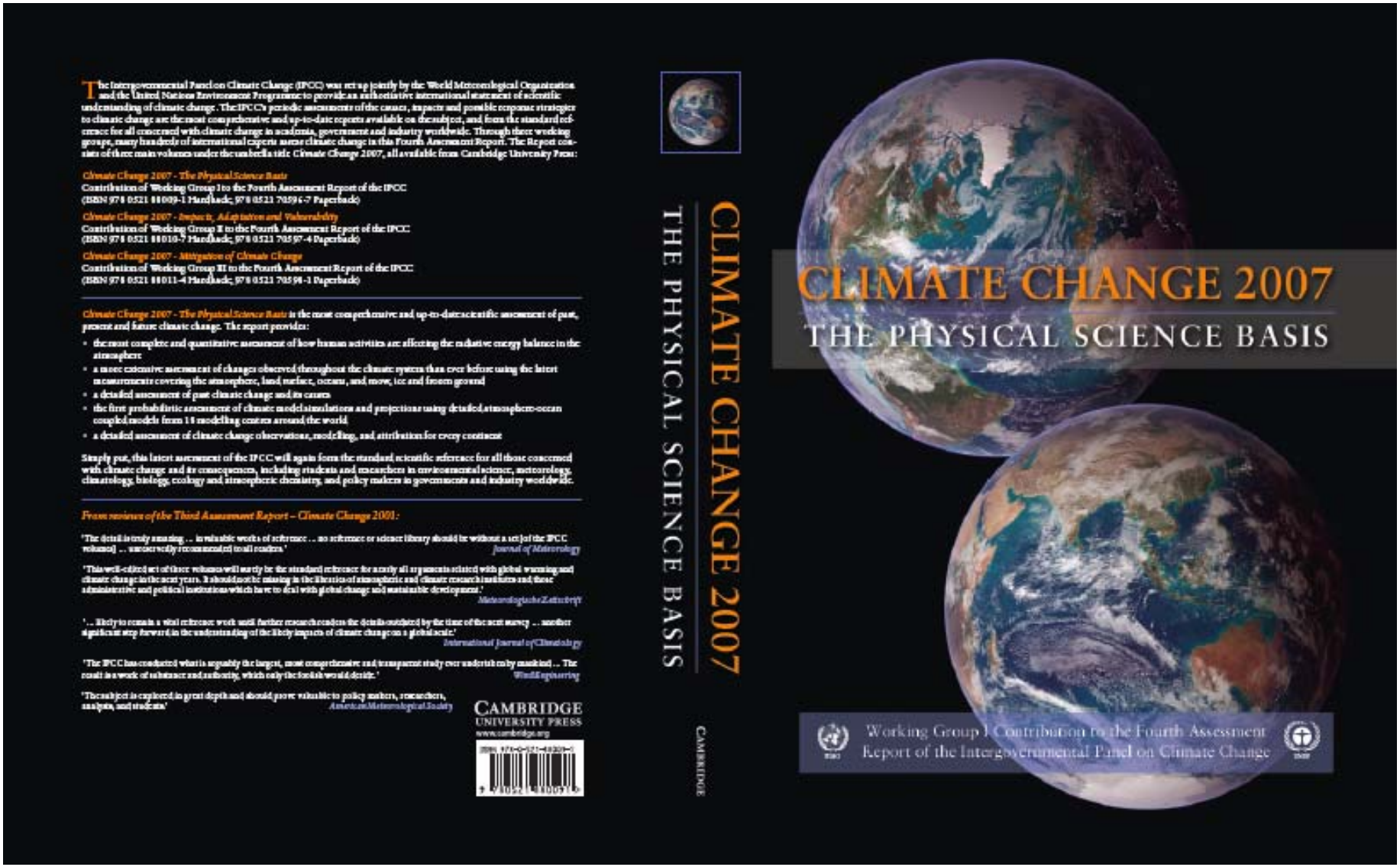
IPCC results: The IPCC WG1 bureau and fellow authors

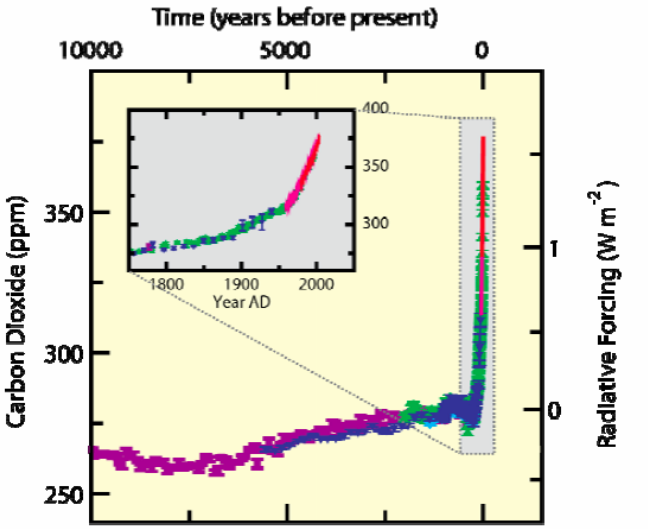
Topics

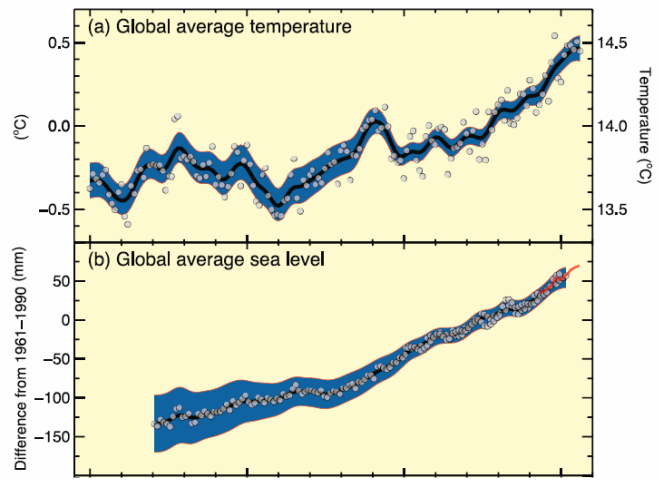
- The global context of regional climate change
  - *Recent changes in global temperature and sea level*
  - *Attribution of these changes to human causes*
  - *Global warming during the 21st century*
- Climate change in the western regional US
- Changes in climatic extremes in the western US
  - *What are climate extremes?*
  - *Projections for temperature and precipitation extremes*
- Future developments in global climate projections

Findings from the new IPCC report



Historical forcing and climate change



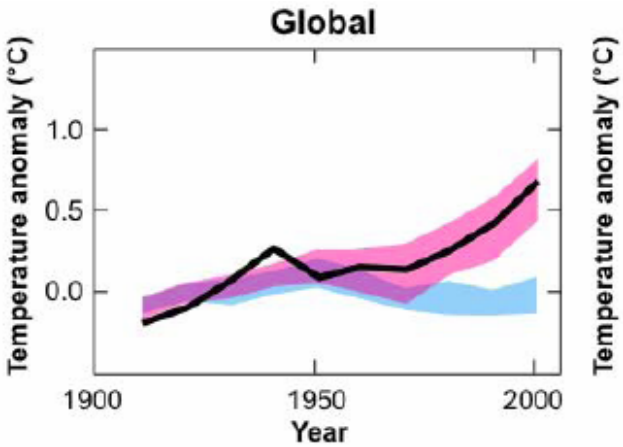


- *CO_2 was constant for almost 10000 years.*
- *CO_2 has risen rapidly in the industrial age.*

- *Temperatures have risen by 0.76K since 1850.*
- *Sea level has risen by roughly 1 foot since 1850.*

IPCC AR4, 2007

Attribution of past climate change



Observations

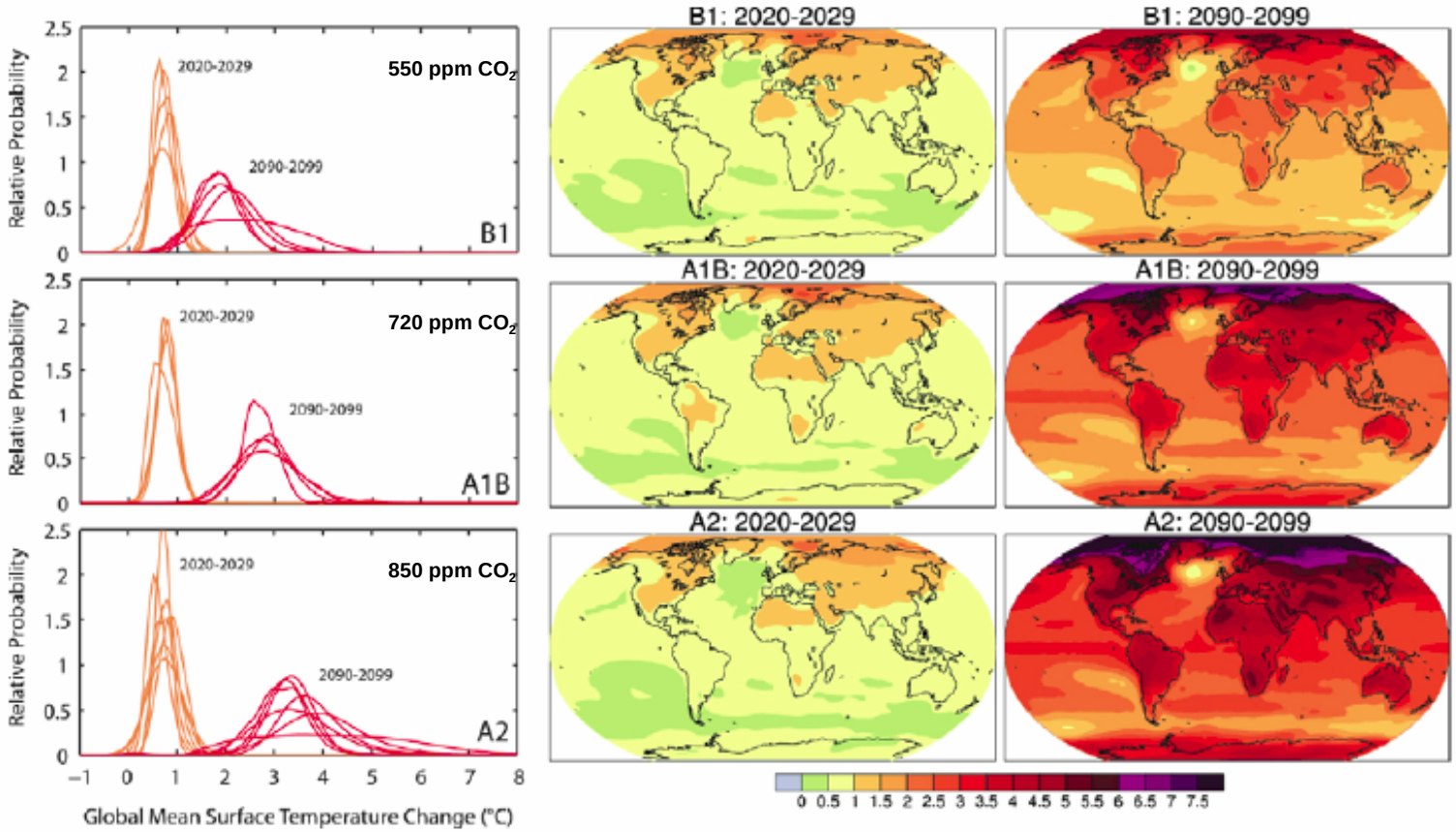
Models with all forcings

Models with natural forcings

- Models with only natural forcings do not match observations.
- It is very likely (>90%) humans are cause of recent warming.

IPCC AR4, 2007

Climate change in the 21st century



- *Warming by 2030 is scenario-invariant and is 2x natural variability.*
- *Warming by 2100 is scenario-dependent and ranges from 1.8 to 4C.*

IPCC AR4, 2007

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Temperature projections for US

QuickTime™ and a
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are needed to see this picture.

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- *Warming by 2100 in western North America is at last 2°C.*
- *Warming increases almost linearly with time.*

IPCC AR4, 2007

Regional temperature projections for 2100

QuickTime™ and a
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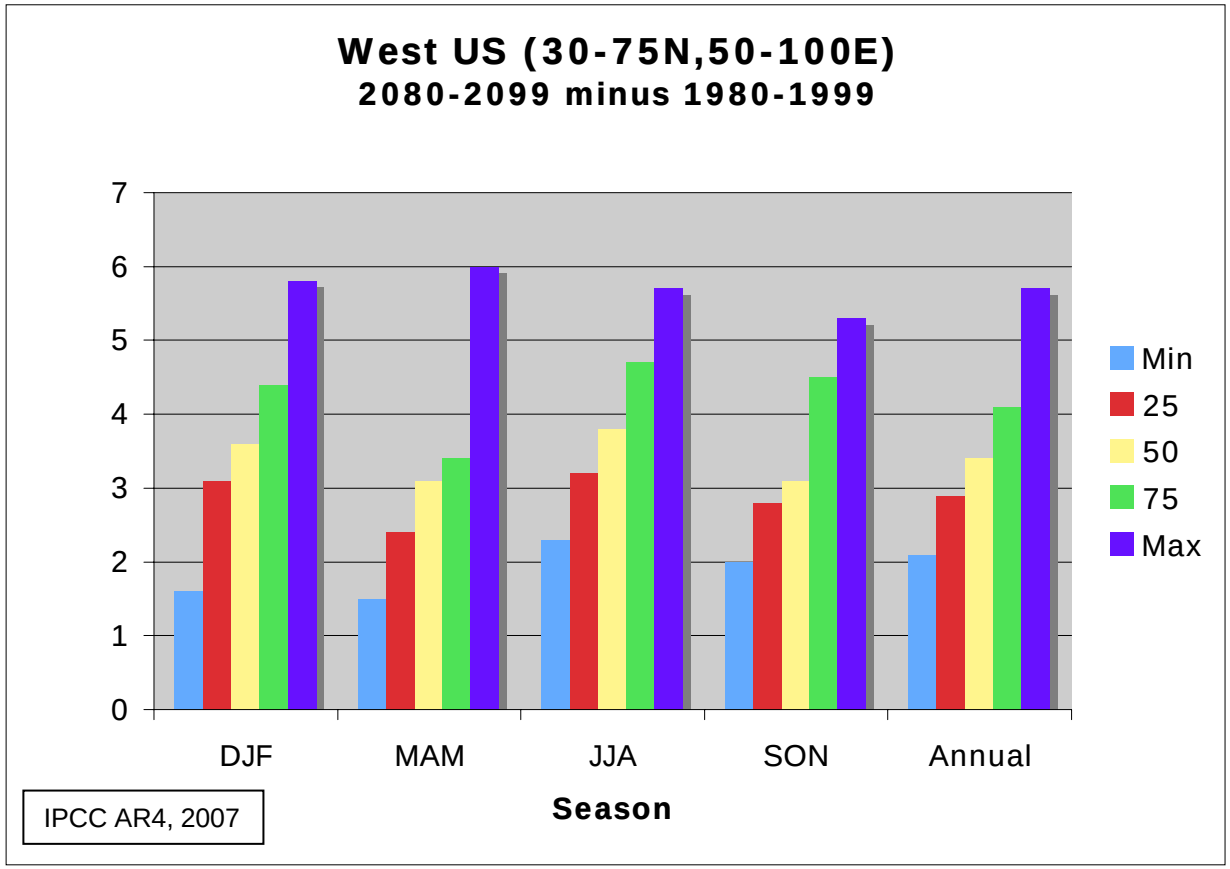
are needed to see this picture.

- *Warming in western North America is largest during summer.*

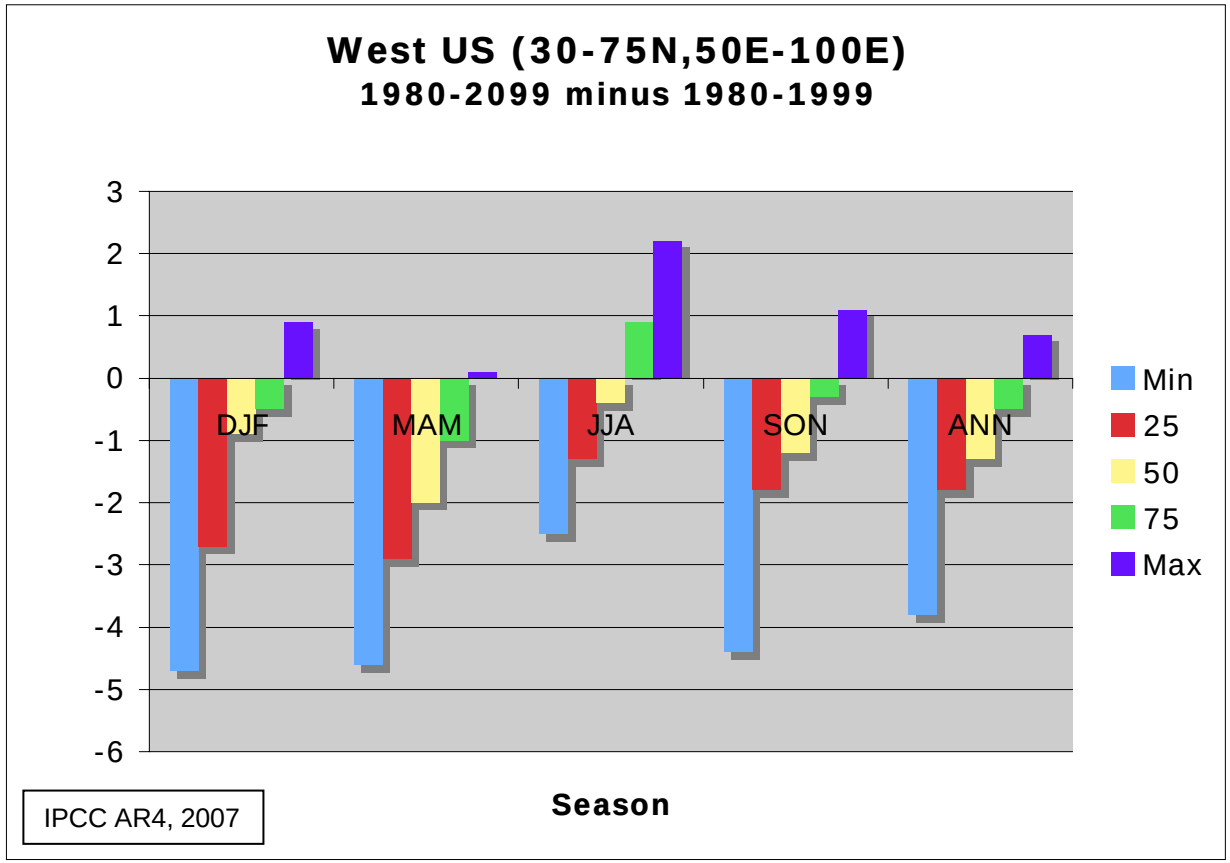
IPCC AR4, 2007

Range in temperature change among models



- *These signals will dominate natural variability after enough time.*
- *Time scale ranges from 10 years (summer) to 25 years (winter).*

Model fidelity for current climate



- *The fidelity of the model projections can be judged using model biases.*
- *The median model biases are much smaller than projected warming.*

Regional precipitation projections for 2100

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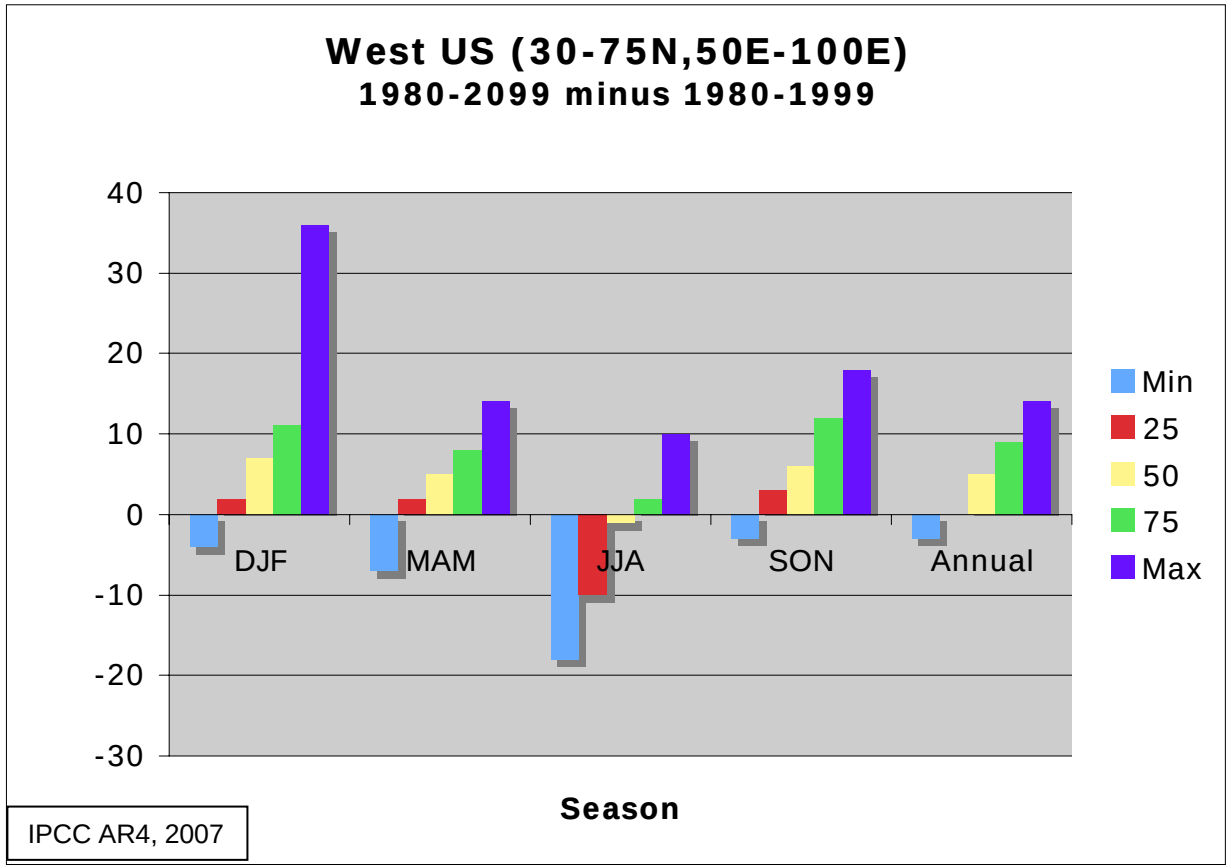
- *Precipitation is displaced northward with the shifting storm tracks.*
- *Subpolar moistening and subtropical drying dominates the projections.*

Model range in precipitation



- *There is a weak trend toward greater precipitation over the western region.*
- *This trend becomes distinct from natural variability at >70 years.*

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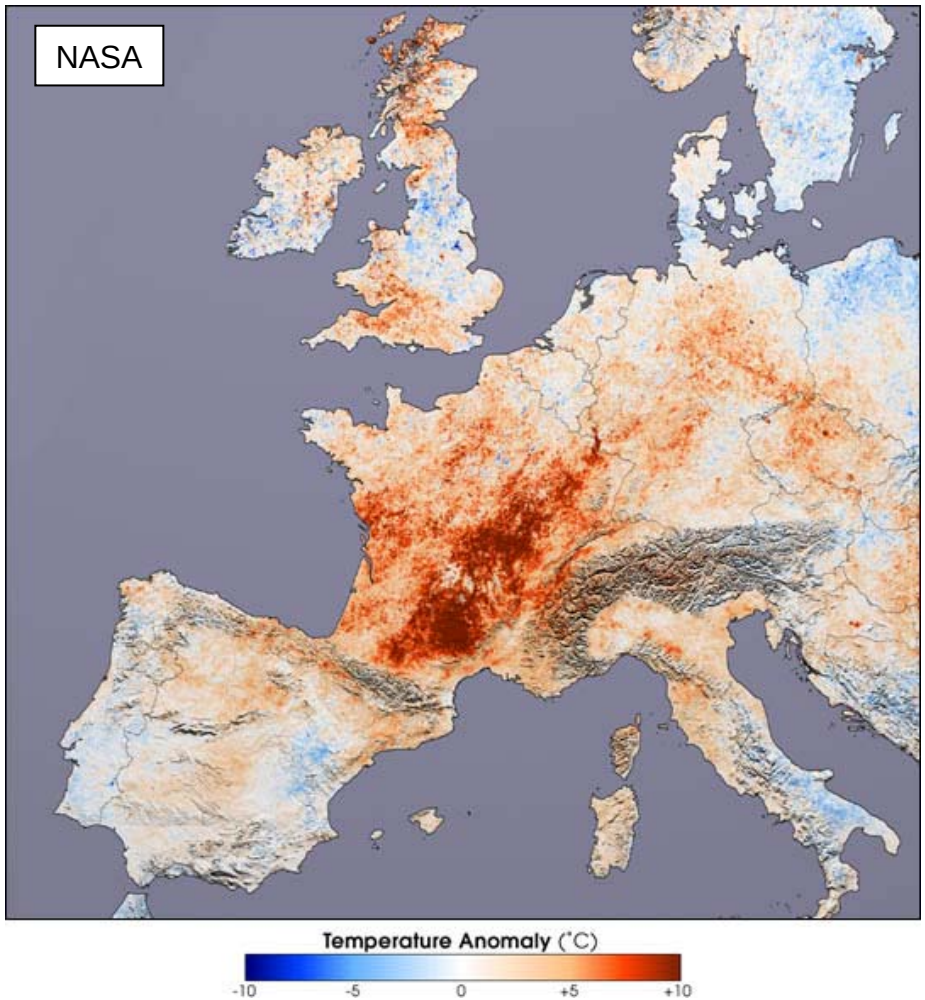
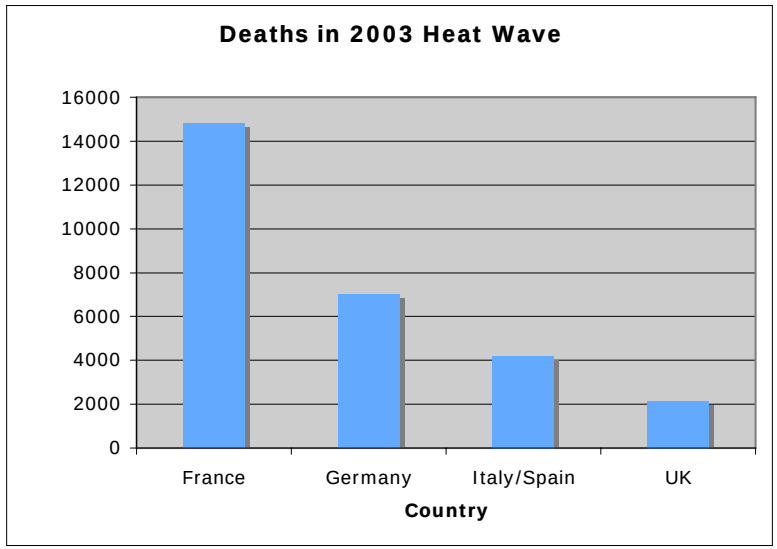
Climate extremes: 2003 European heat wave

August 2003 temperature anomalies





What is a climate extreme?

Monthly average August 2003 temperatures

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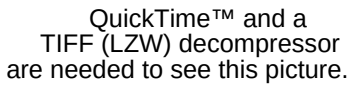
are needed to see this picture.

IPCC AR4, 2007

An extreme is a climatologically unusual condition -
In the case of the European heat wave, high temperature.

Shifts in climatic “bell curve” can cause extremes

Summer daily maximum temperatures



IPCC AR4, 2007

Extremes analysis (I)

- Objective:

  Project regional changes in *climate extremes indices* for temperature and precipitation over the 21st century

- Climate extremes indices:

  Measures of local change in extreme events such as heat waves, heavy rain or snow events, and droughts

- Selection of 10 indices of climate extremes:

  - *These indices capture a wide spectrum of climate extreme characteristics.*
  - *These indices are robust despite measurement and predictive uncertainty.*

- Source of projections:

  Nine climate models used in the 4th IPCC assessment

Extremes analysis (II)

- Definition of the indices of climate extremes
- Sources of uncertainty in projections for these indices
- The models used to project these indices for 2000-2100
- The scenarios used for future emissions of greenhouse gases
- Schema for the regional projections
- Regional projections for *North America*

Climate extreme indices for temperature

- **Total number of frost days:**
  Annual number of days with absolute minimum temperature below 0^{o} C

- **Growing season length:**
  Length of period between first and last 5 consecutive days with mean temperature above 5^{o} C

- **Warm nights:**
  Percentage of times in year when minimum temperature is above the 90th percentile of the climatological distribution for that calendar day

- **Intra-annual extreme temperature range:**
  Difference between highest and lowest temperature of the year

- **Heat wave duration index:**
  Maximum period of at least 5 consecutive days with maximum temperature higher by at least 5^{o} C than the climatological norm

Climate extreme indices for precipitation

- **Simple daily intensity index:**
  Annual total precipitation divided by number of wet days with rainfall greater than 1 mm
- **Maximum 5-day total precipitation**
- **Fraction of total precipitation from events exceeding 95th percentile**
- **Number of days with precipitation greater than 10 mm**
- **Maximum number of consecutive dry days:**
  Rainfall less than 1 mm on each day

Sources of uncertainty in climate extremes

- **Uncertainty in future emissions:**
  - *Resolution: project changes for a wide range of* emissions scenarios
- **Uncertainty in the accuracy of projections from any single climate model:**
  - *Resolution: project changes using a wide variety of* atmosphere-ocean general circulation models

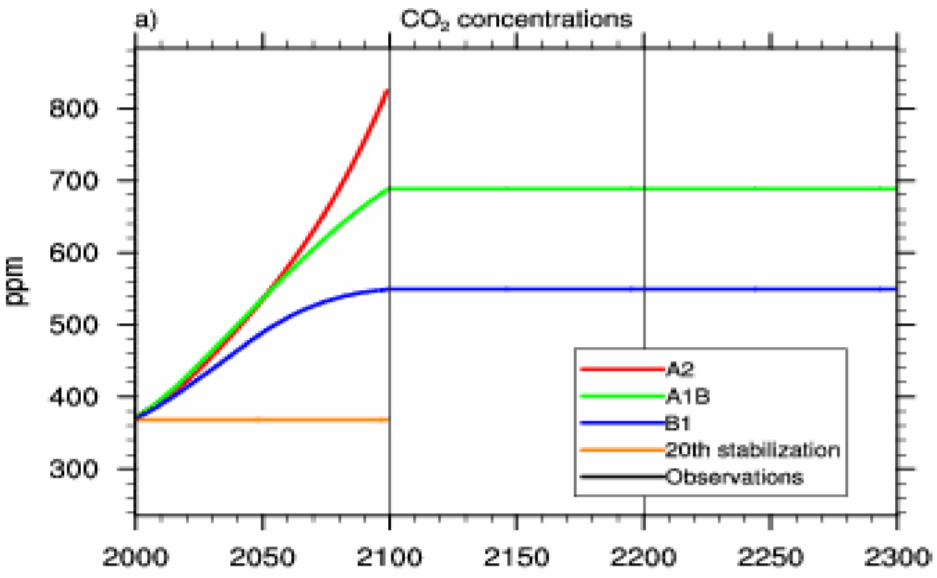
Models in multi-model ensemble

TABLE I
The nine Atmosphere-Ocean General Circulation Models featured in our analysis

Modeling center	AOGCM	Climate sensitivity (TCR)
National Center for Atmospheric Research (USA)	CCSM3	1.46
Météo-France & Centre National de Recherches Météorologiques (France)	CNRM-CM3	1.57
US Dept. of Commerce & National Oceanic and Atmospheric Administration & Geophysical Fluid Dynamics Laboratory (USA)	GFDL-CM2.0	1.60
US Dept. of Commerce & National Oceanic and Atmospheric Administration & Geophysical Fluid Dynamics Laboratory (USA)	GFDL-CM2.1	1.50
Institute for Numerical Mathematics (Russia)	INM-CM3	1.57
Center for Climate System Research & National Institute for Environmental Studies & Frontier Research Center for Global Change (JAPAN)	MIROC3.2(medres)	2.11
Center for Climate System Research & National Institute for Environmental Studies & Frontier Research Center for Global Change (JAPAN)	MIROC3.2(hires)	NA
Department of Energy & National Center for Atmospheric Research (USA)	PCM	1.32
Meteorological Research Institute & Japan Meteorological Agency (Japan)	MRI-CGCM2	0.97

Tebaldi et al, 2006

Scenarios for future emissions



IPCC emissions scenarios:

- A2:

  A very heterogeneous world with continuously increasing global population and regionally oriented economic growth that is more fragmented and slower than in other scenarios.

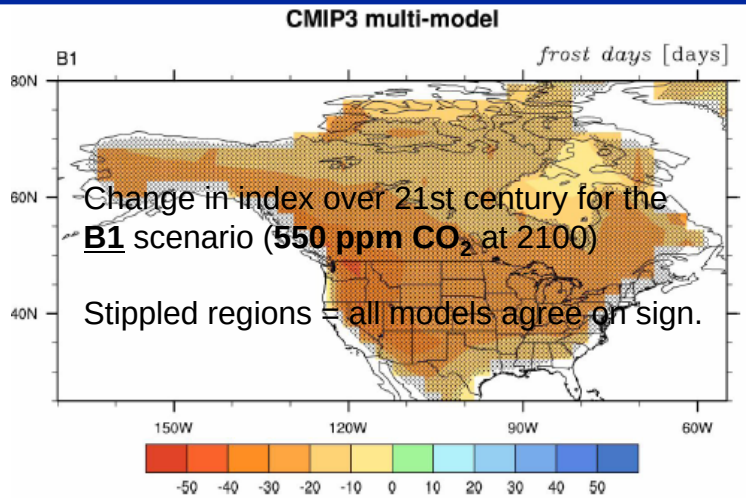
- A1B:

  A future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and rapid introduction of new and more efficient technologies.

- B1:

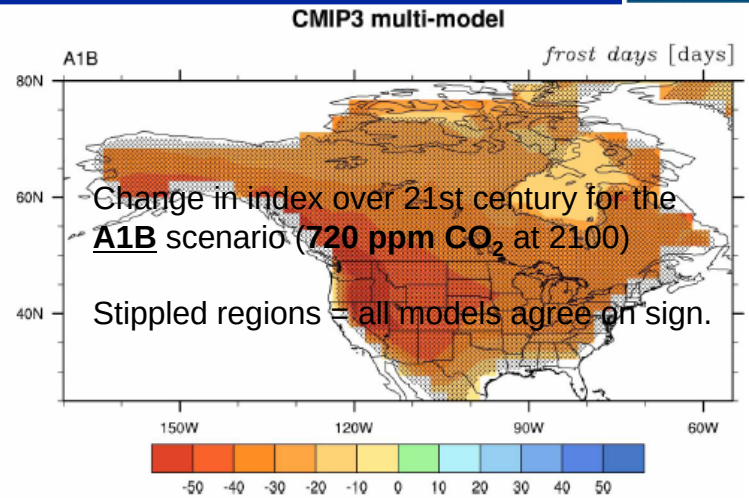
  A convergent world with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies.

Schema: Climate index maps & series



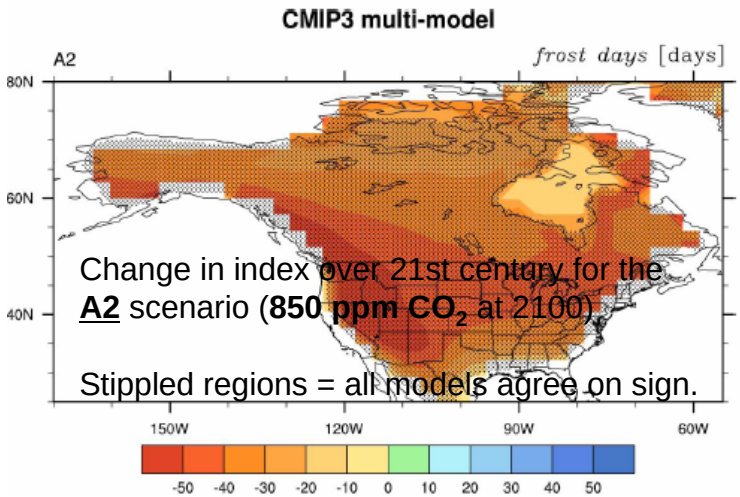
Change in index over 21st century for the **B1** scenario (**550 ppm CO_2** at 2100)

Stippled regions = all models agree on sign.



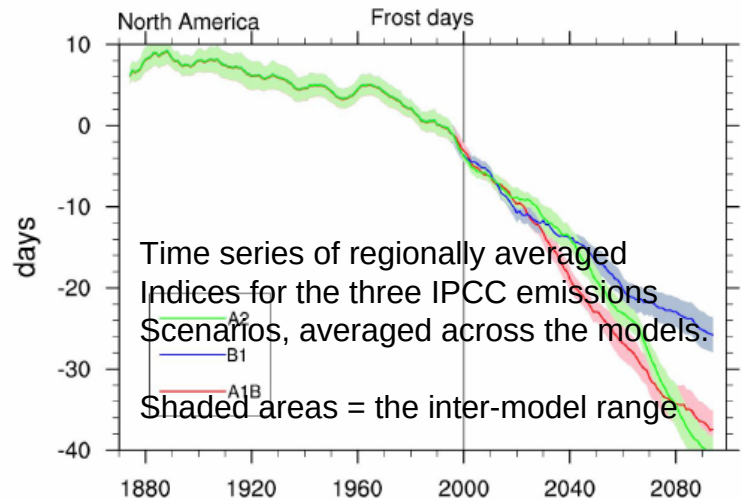
Change in index over 21st century for the **A1B** scenario (**720 ppm CO_2** at 2100)

Stippled regions = all models agree on sign.



Change in index over 21st century for the **A2** scenario (**850 ppm CO_2** at 2100)

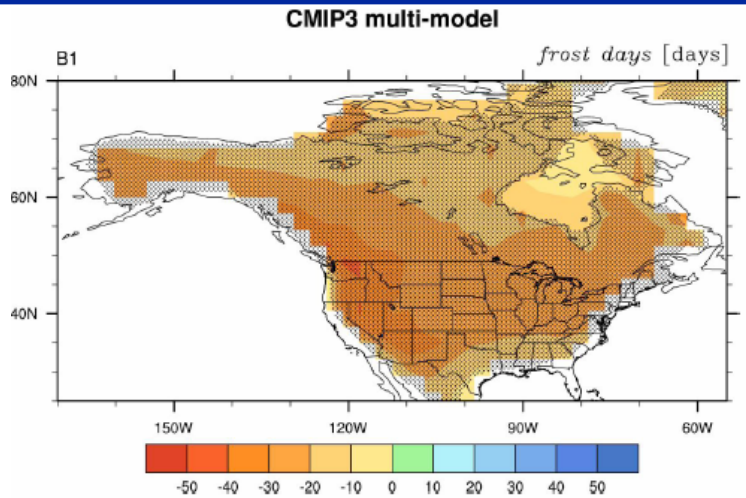
Stippled regions = all models agree on sign.

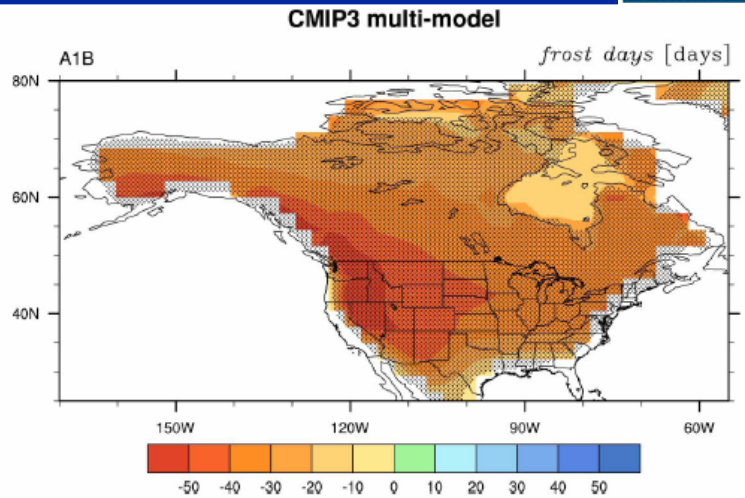


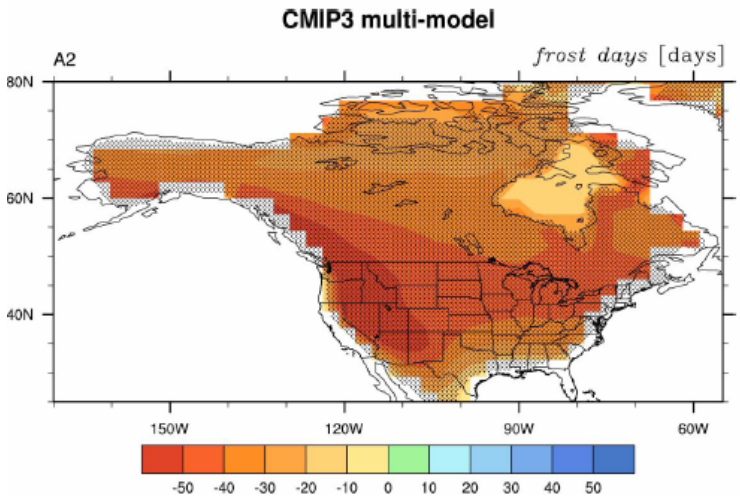
Time series of regionally averaged Indices for the three IPCC emissions Scenarios, averaged across the models.

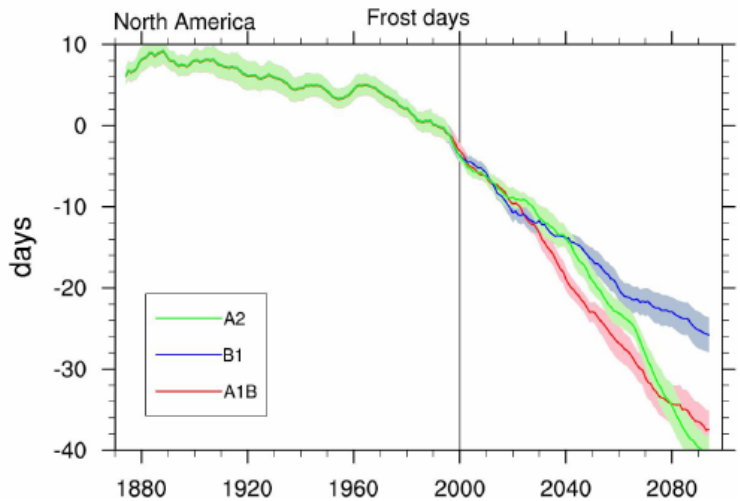
Shaded areas = the inter-model range

Number of frost days

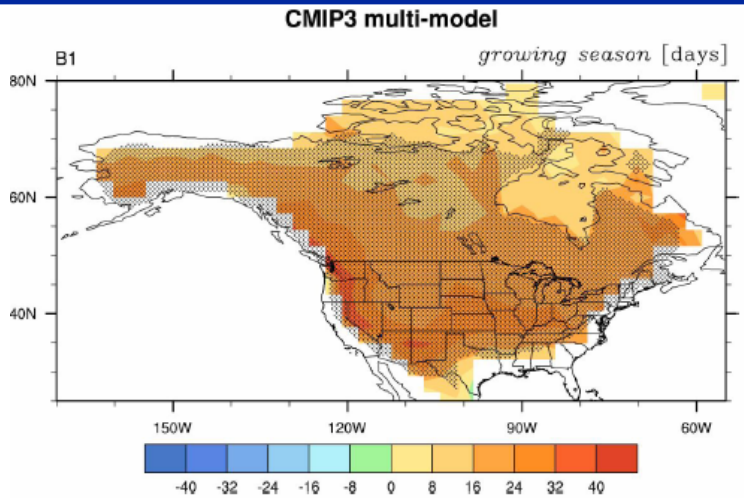


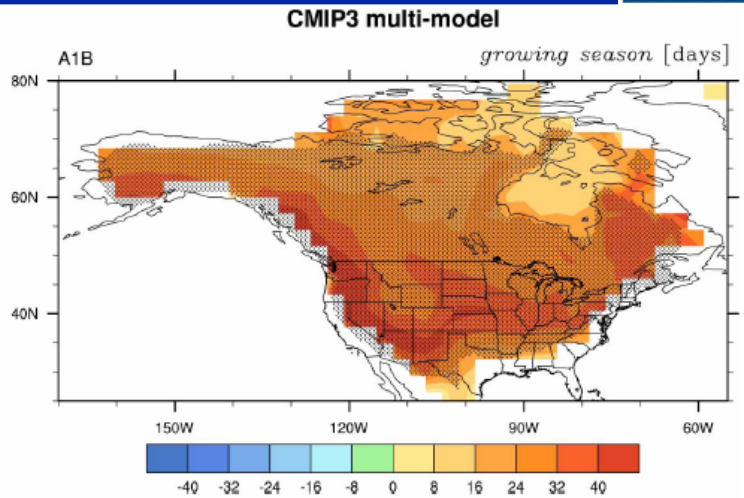


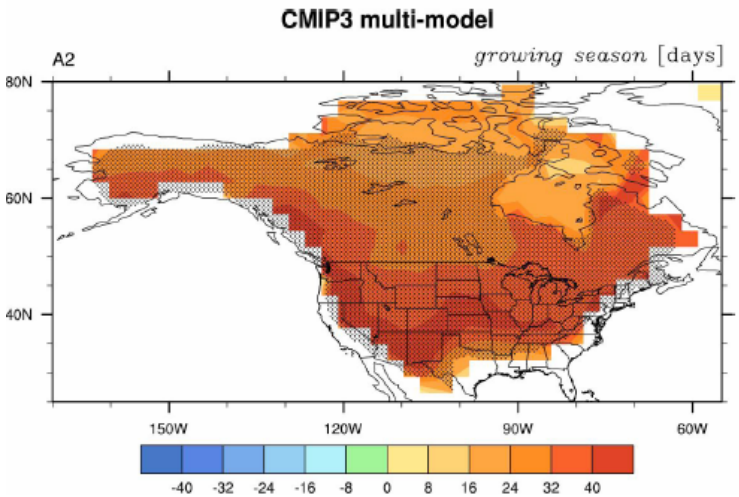


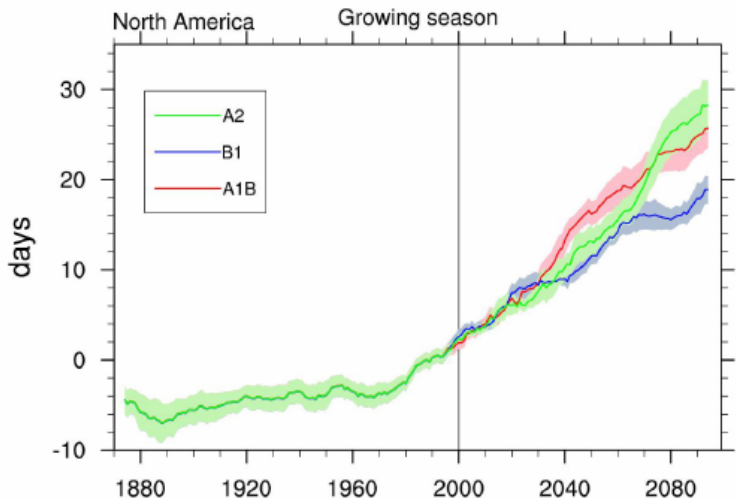


Growing season length

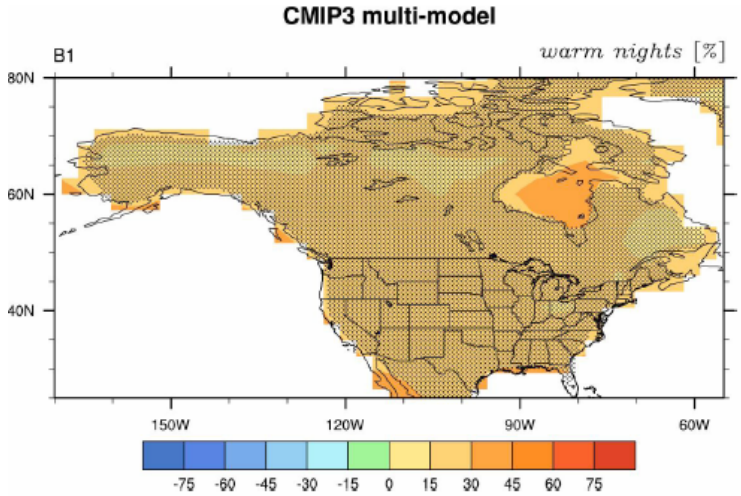


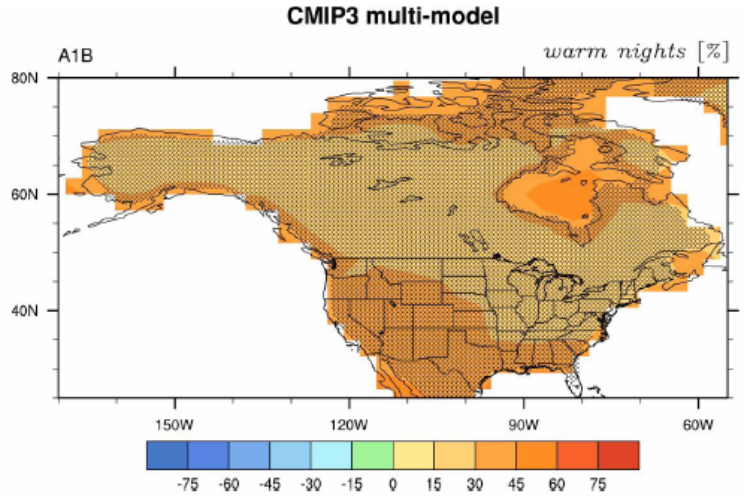


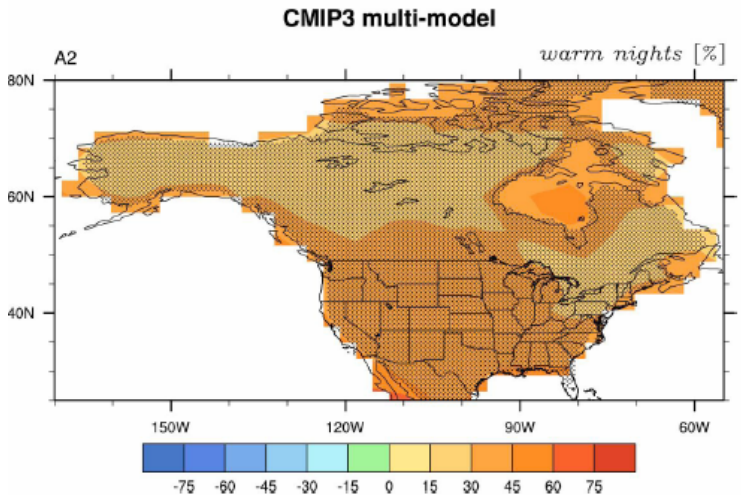


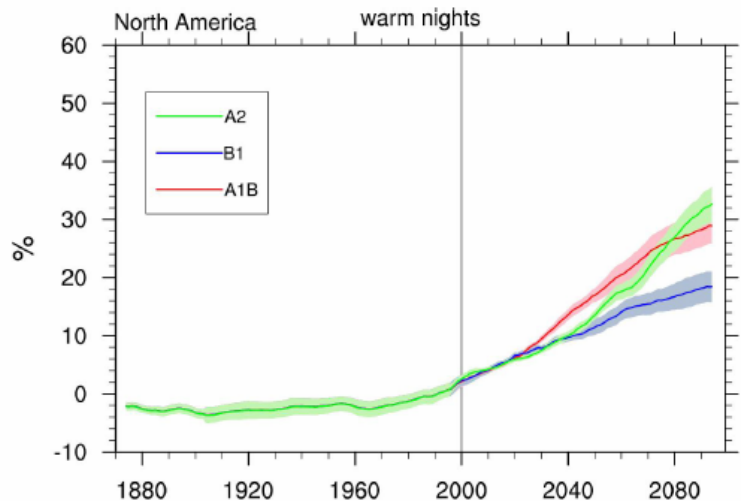


Percentage of warm nights

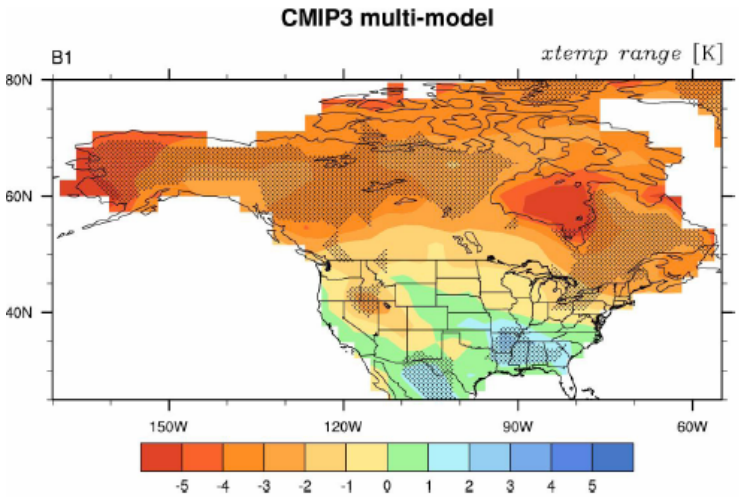


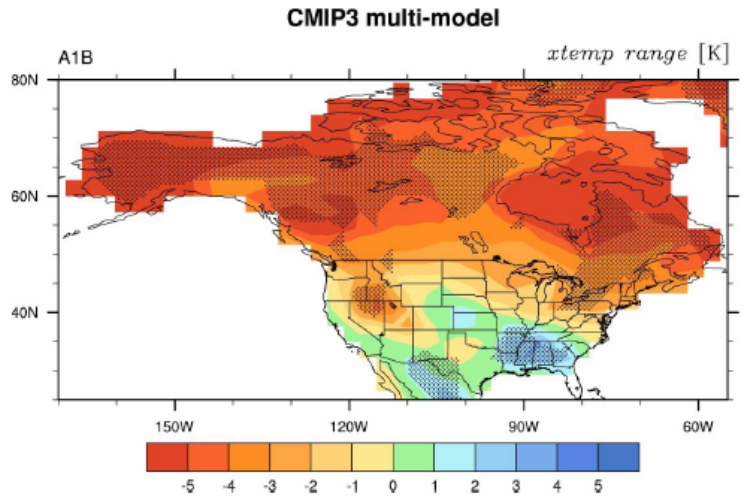


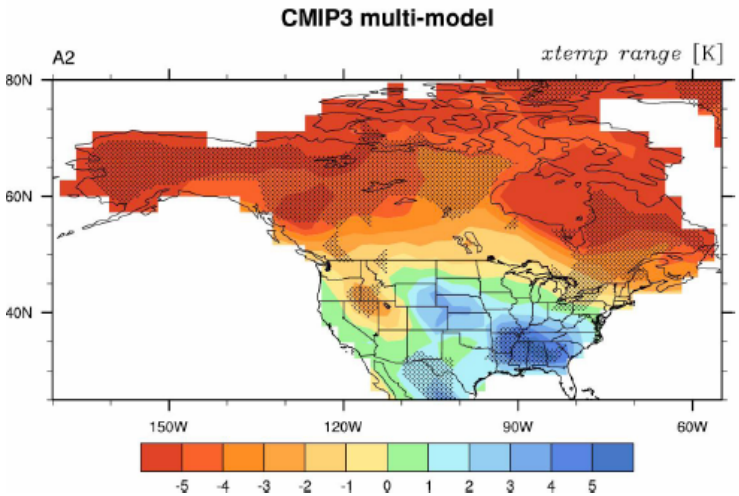


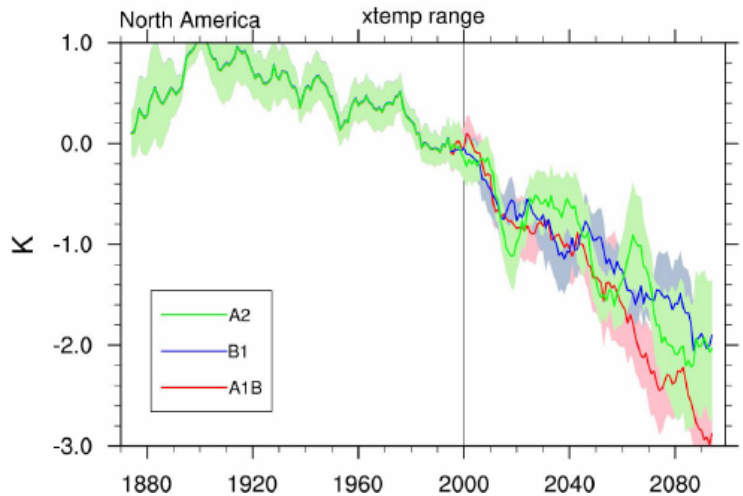


Extreme temperature range

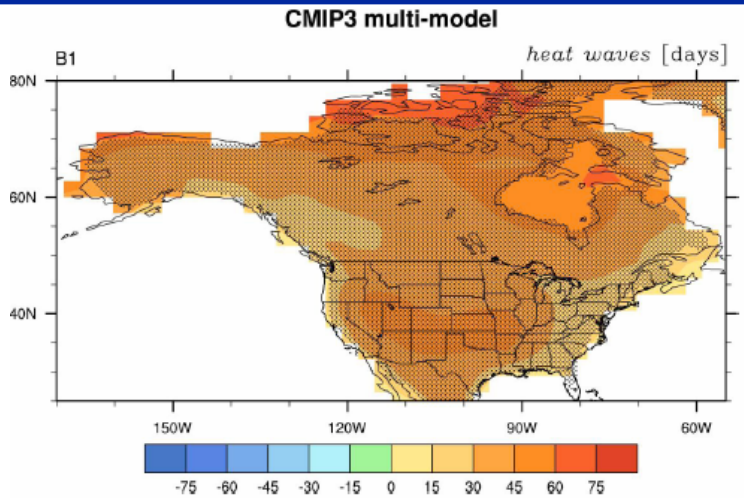


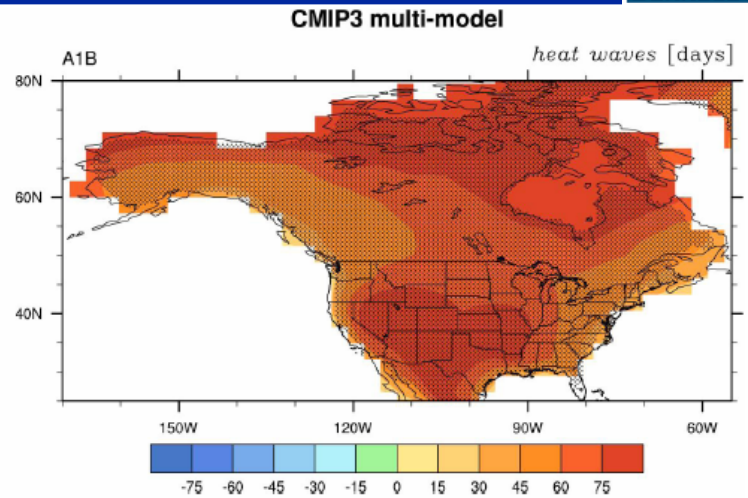


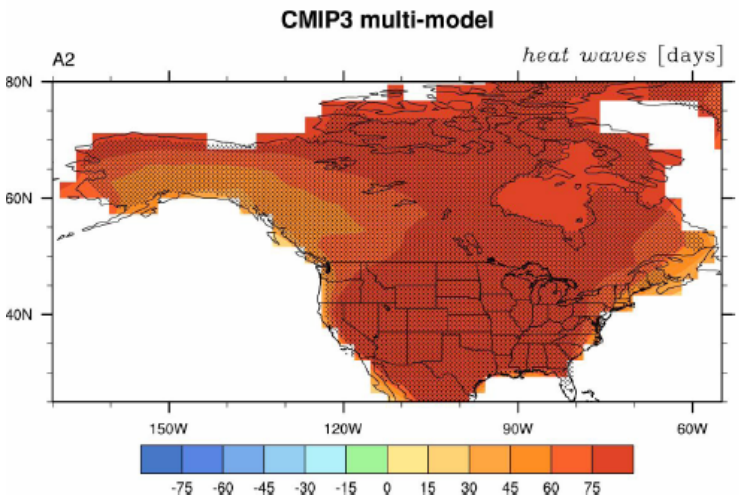


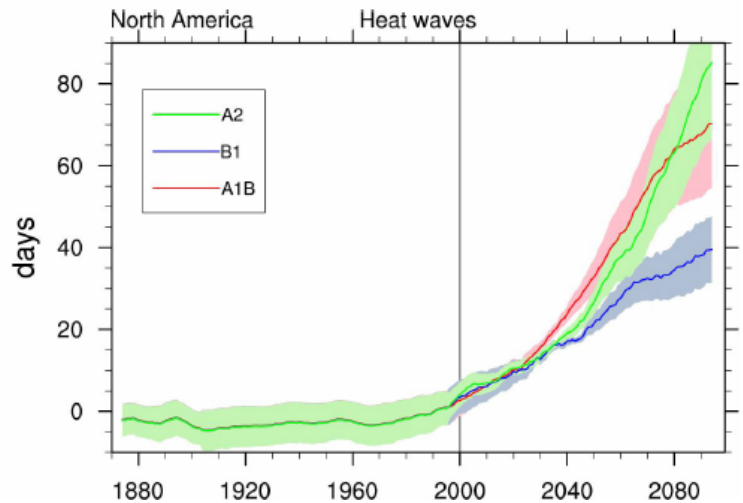


Heat wave duration

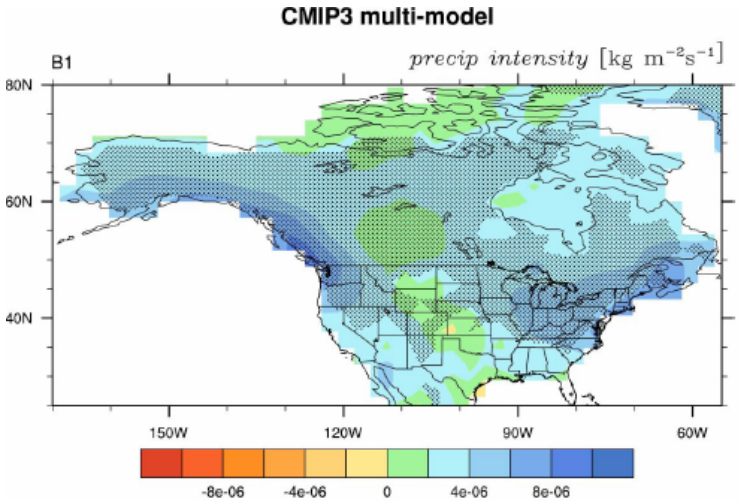


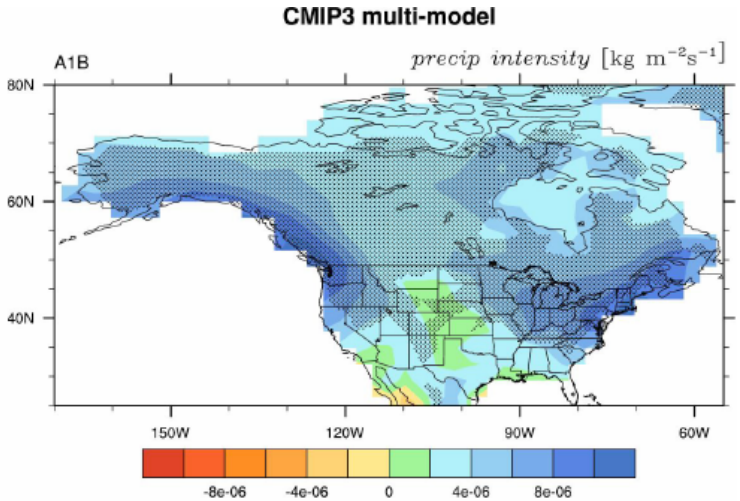




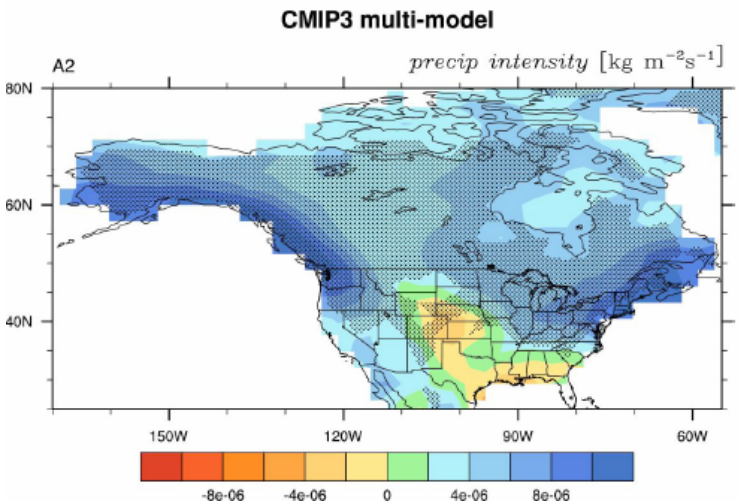


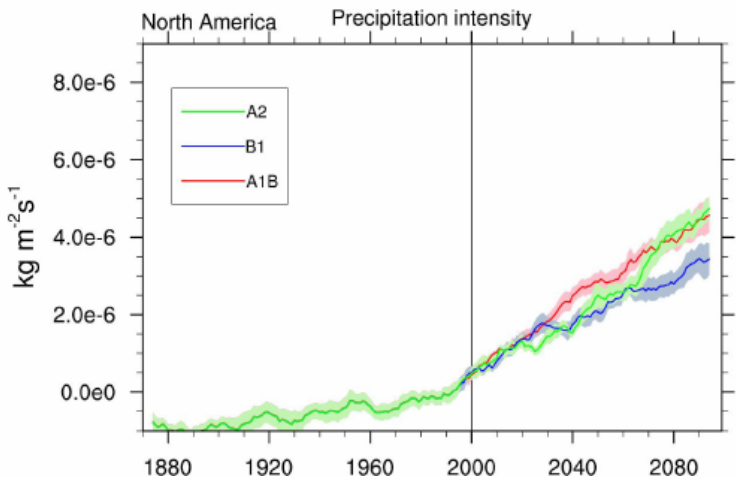
Precipitation intensity



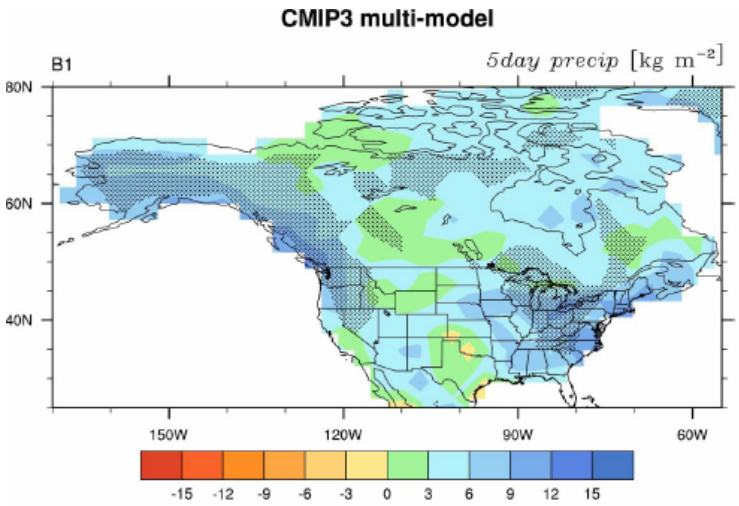


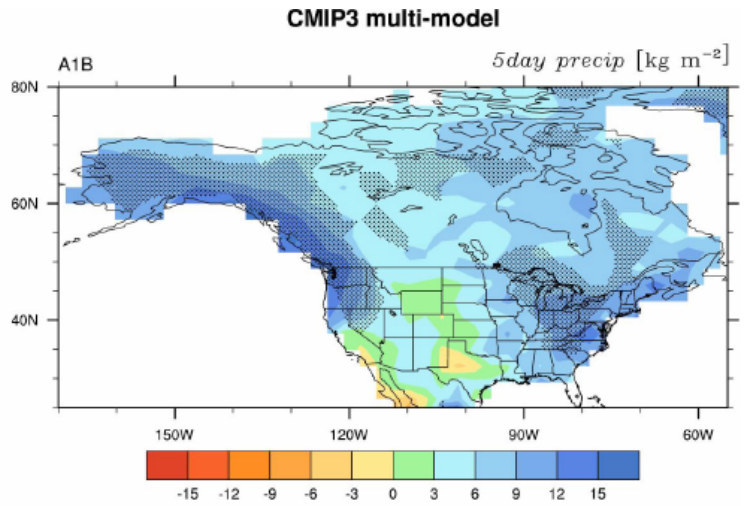
1.0e-5 kg m^{-2} s^{-1} ~ 1 mm/day

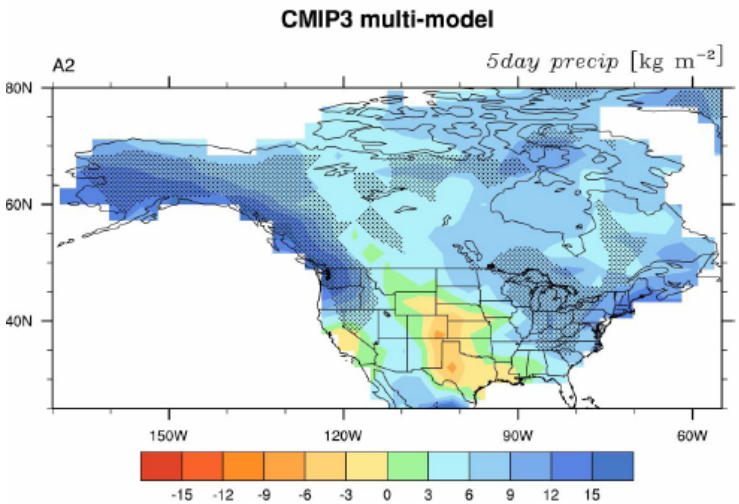




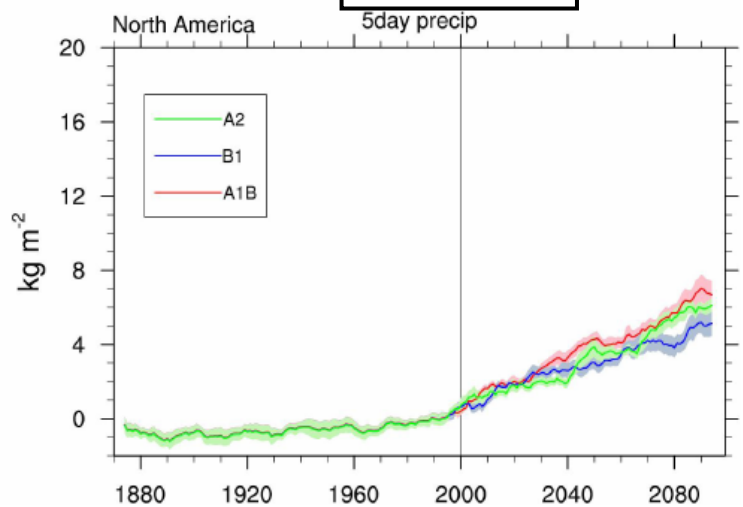
Maximum 5-day precipitation



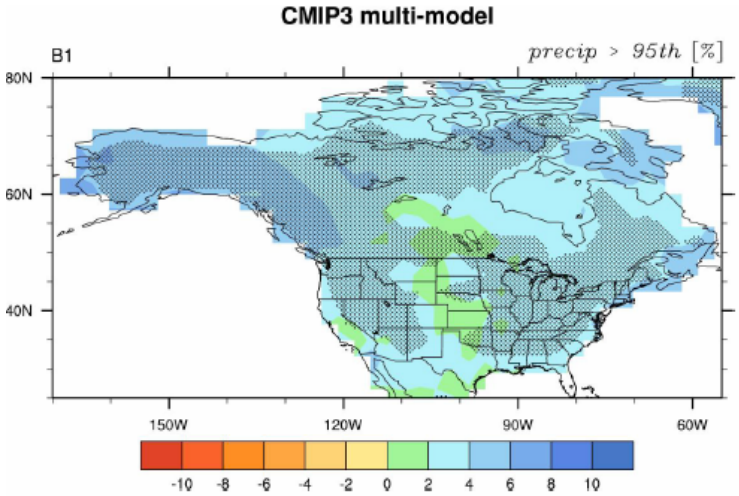


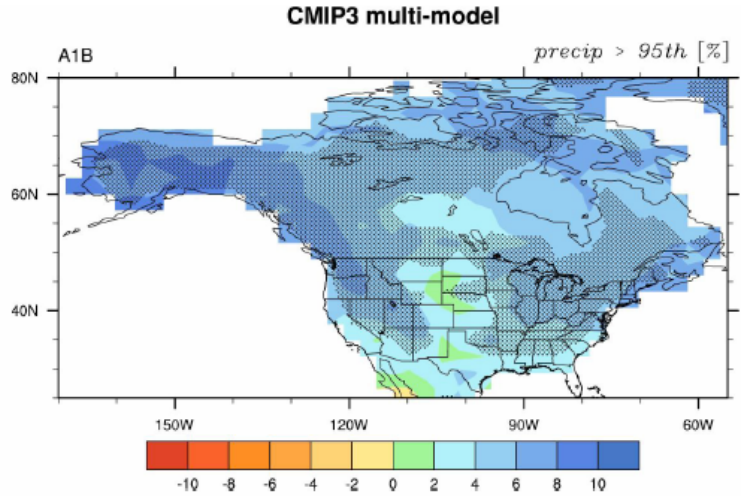


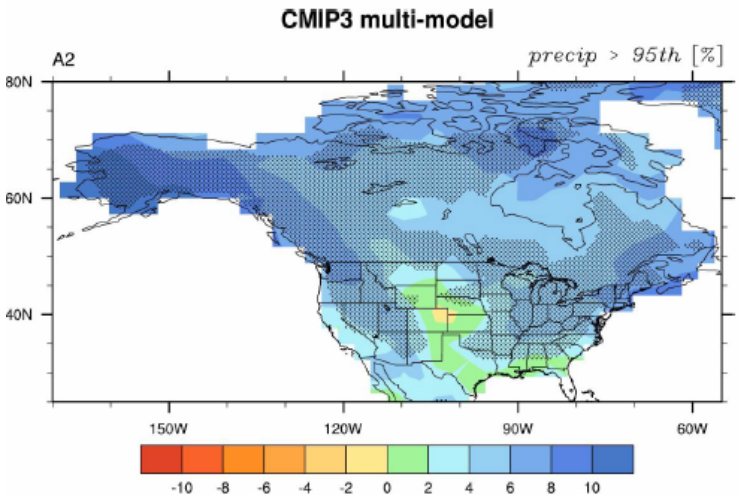
1 kg m^{-2} = 1 mm

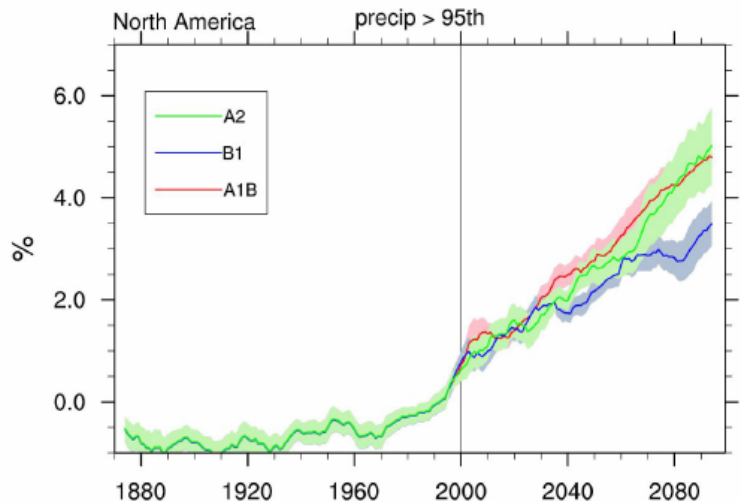


Precipitation fraction > 95th percentile

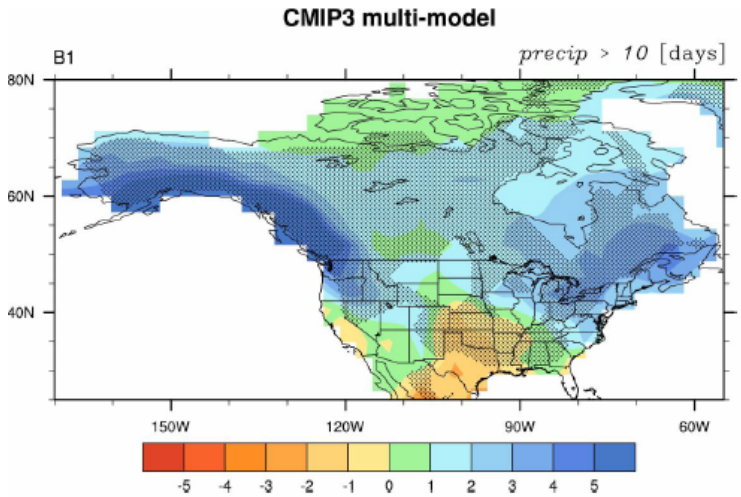


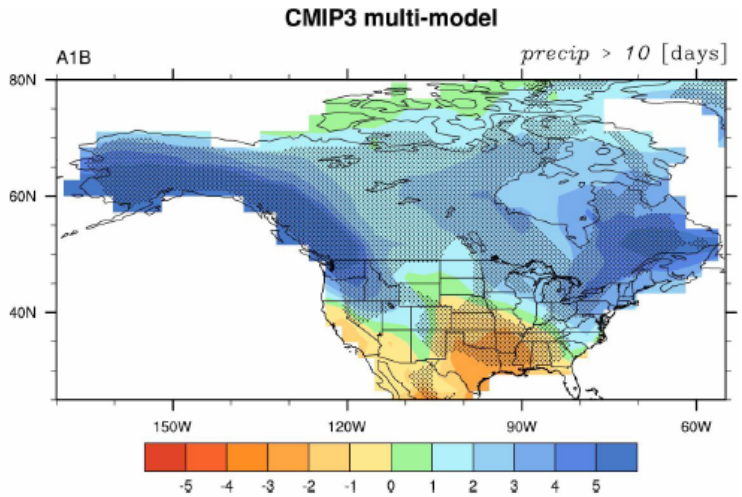


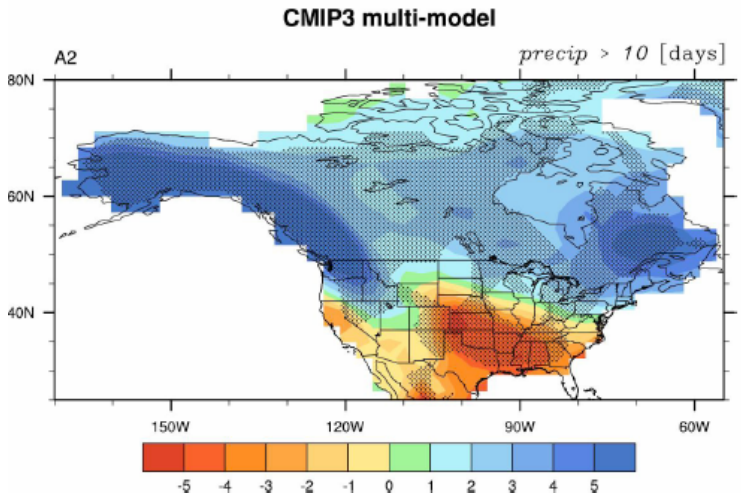


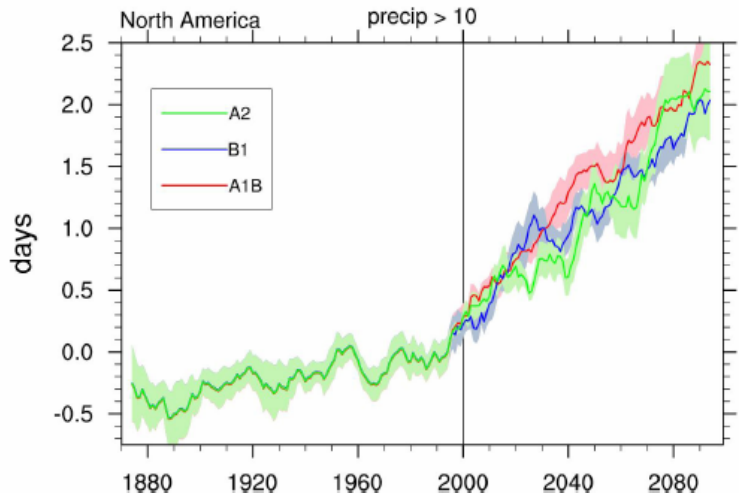


Days with precipitation > 1 cm

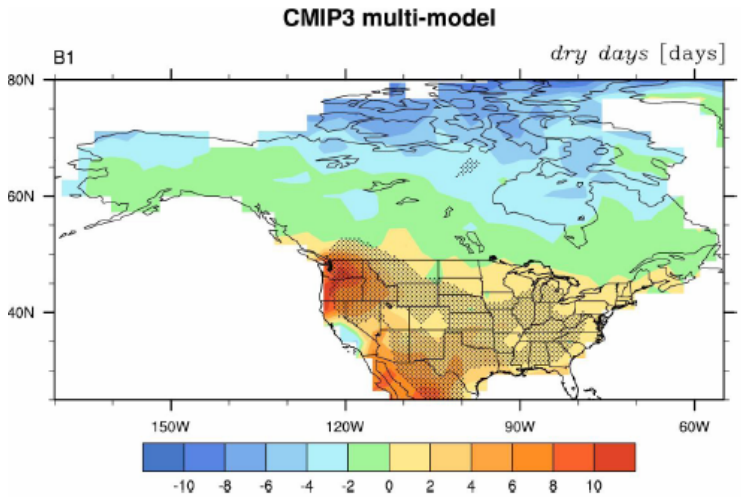


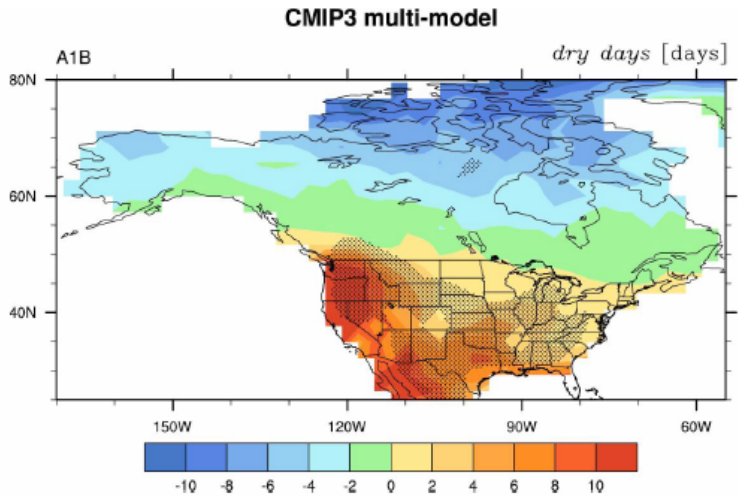


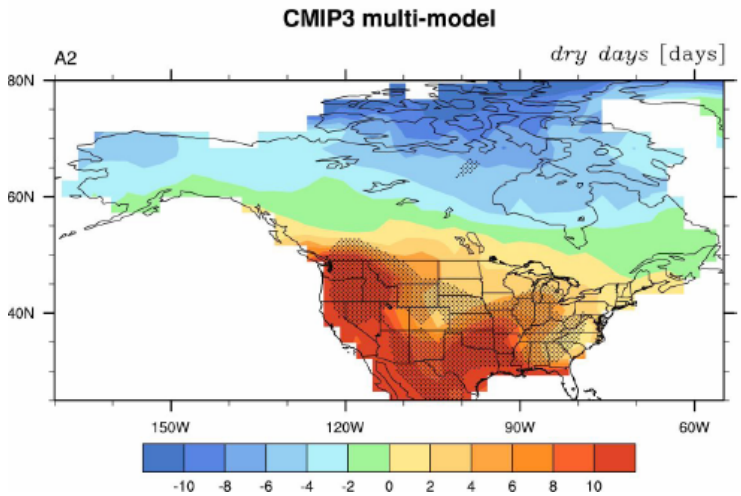


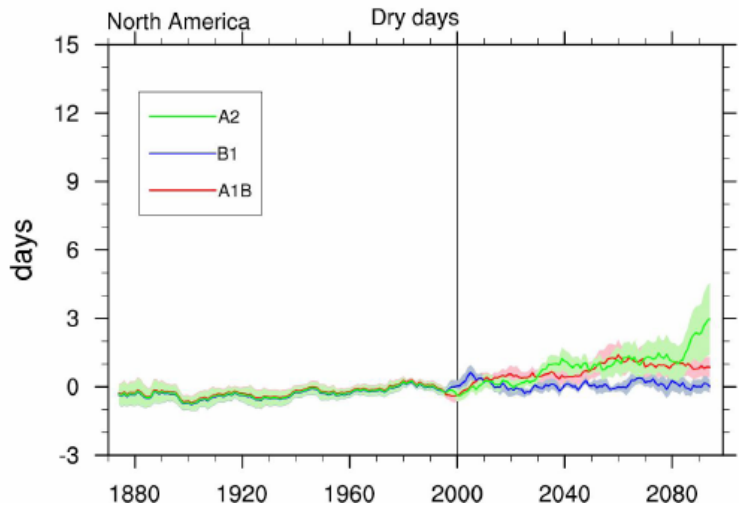


Maximum number of dry days









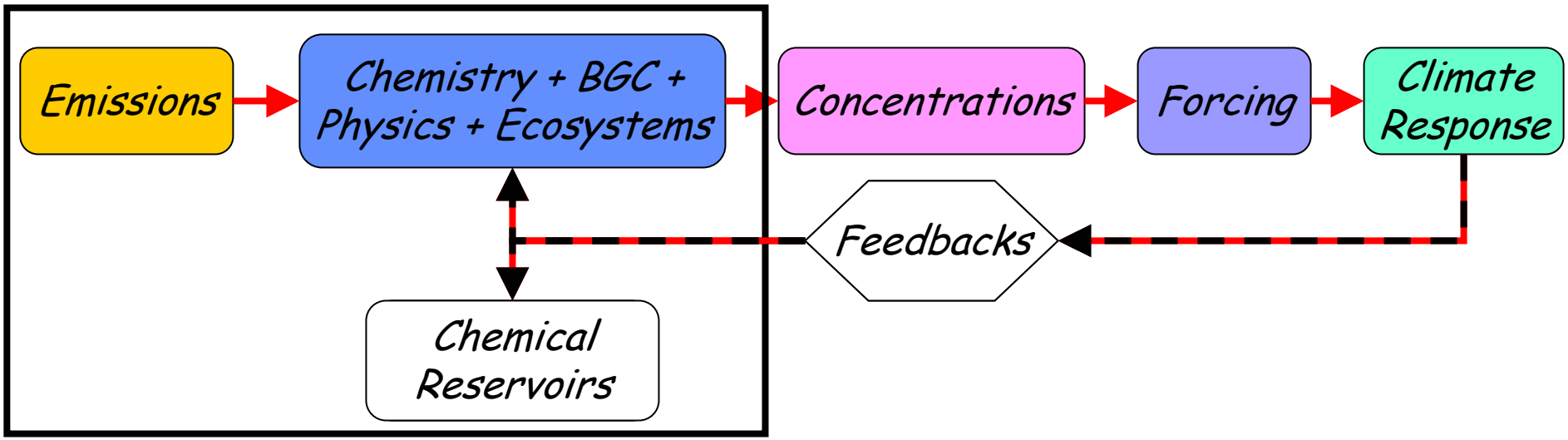
Conclusions regarding extremes

- Longer duration, more intense, and more frequent summer heat waves and hot spells are *very likely*.
- Fewer frost days are *very likely.*
- A reduction in the diurnal temperature range is *likely*.
- Increases in number and duration of dry spells are *likely.*

Topics

- The global context of regional climate change
- Climate change in the western regional US
- Changes in climatic extremes in the western US
- Future developments in global climate projections:
  - *Development of Earth system models*
  - *High-resolution models for regional forecasts*
  - *Short-range climate predictions for adaptation*
  - *Coupled climate / policy models*

Simulating the Earth system

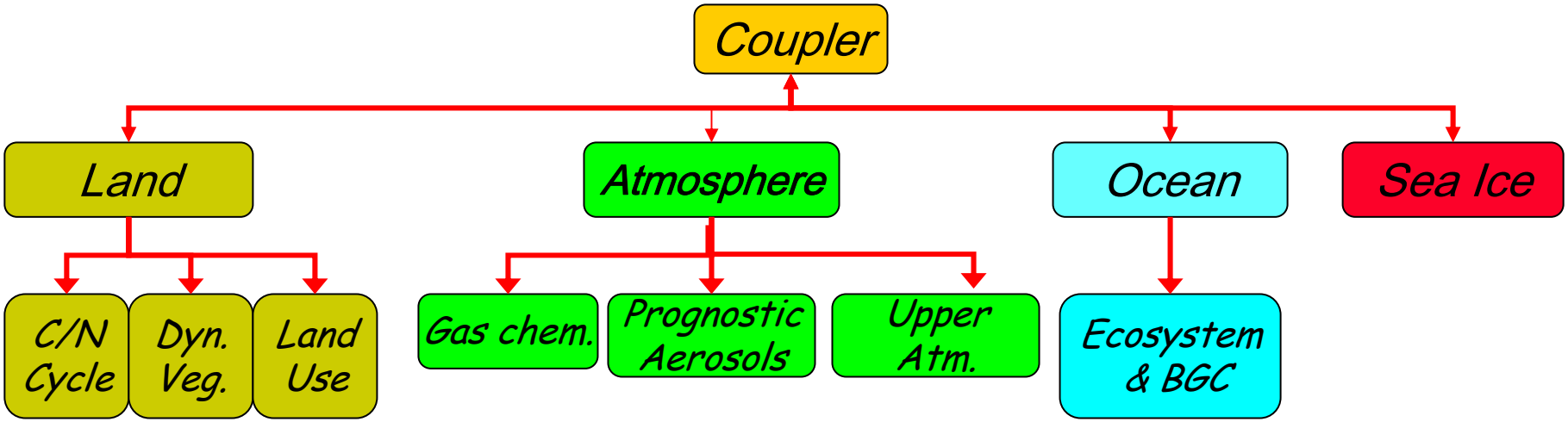


- Climate models prescribe the emissions, chemistry, and carbon cycle.

- This approach is simple to implement, but it omits:
  - Chemical and biogeochemical feedbacks.
  - Chemical and biogeochemical reservoirs.

- The next generation of Earth system models will include these interactions.

Advances in global climate modeling:
NCAR-DOE CCSM Earth System Model



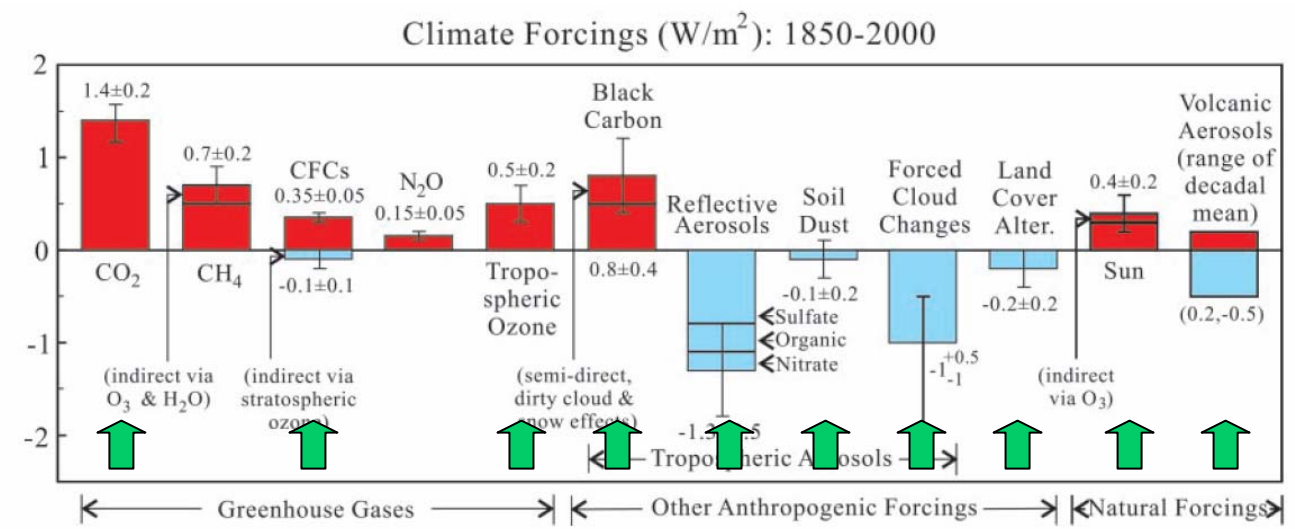
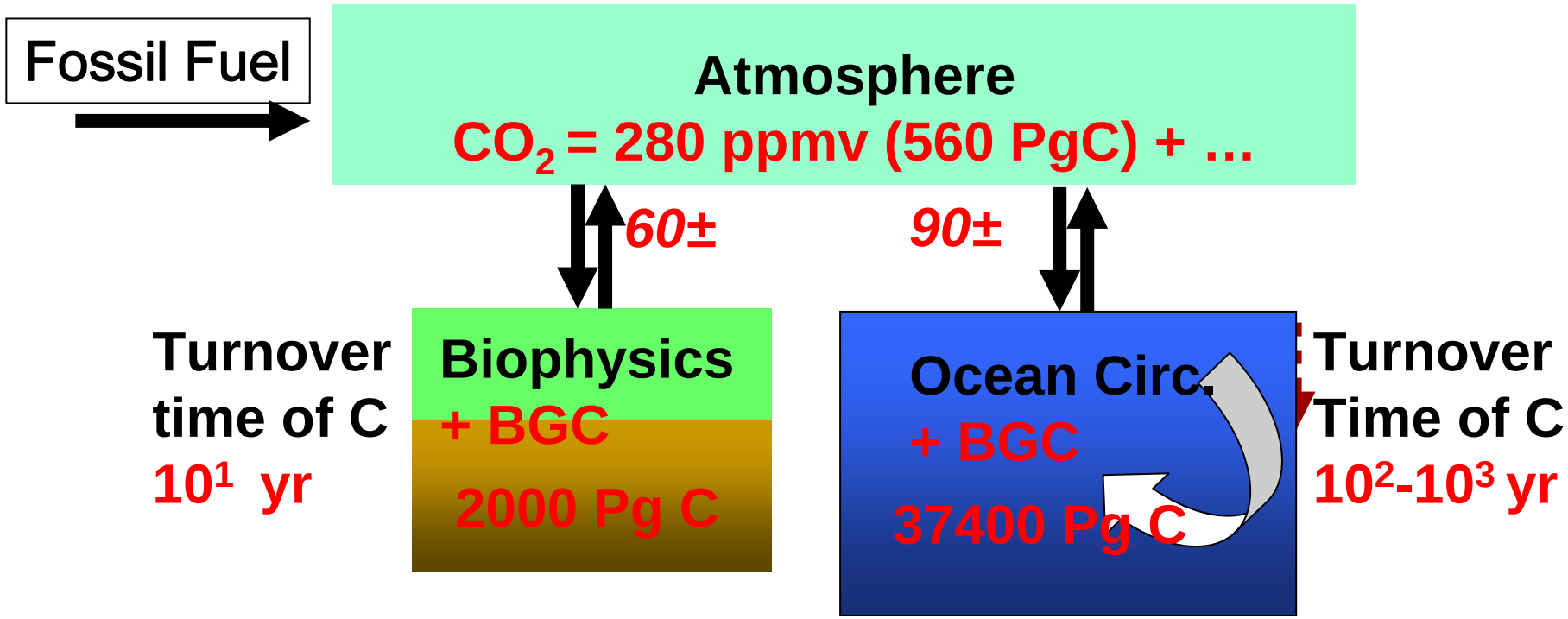


Fig. 1. Estimated climate forcings; error bars are partly subjective 1σ uncertainties.

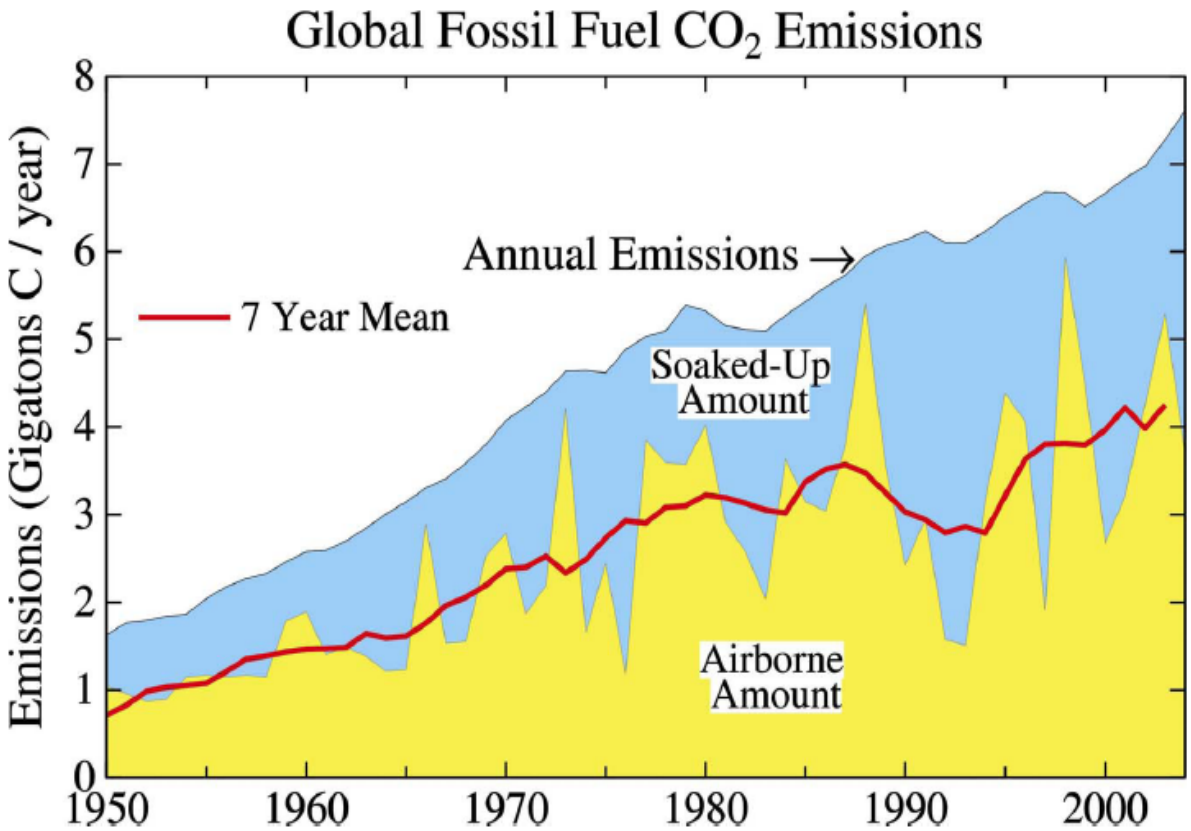
Will the warming accelerate the warming?

Capacities of land and ocean to store carbon are changing.



Outstanding questions

- **Only half of the CO_2 produced by human activities is remaining in the atmosphere**
- **Where are the *sinks* that are absorbing over 40% of the CO_2 that we emit?**
  - ***Land or ocean?***
  - ***Eurasia/North America?***
- **Why does CO_2 buildup vary dramatically with nearly uniform emissions?**
- **How will CO_2 sinks respond to climate change?**

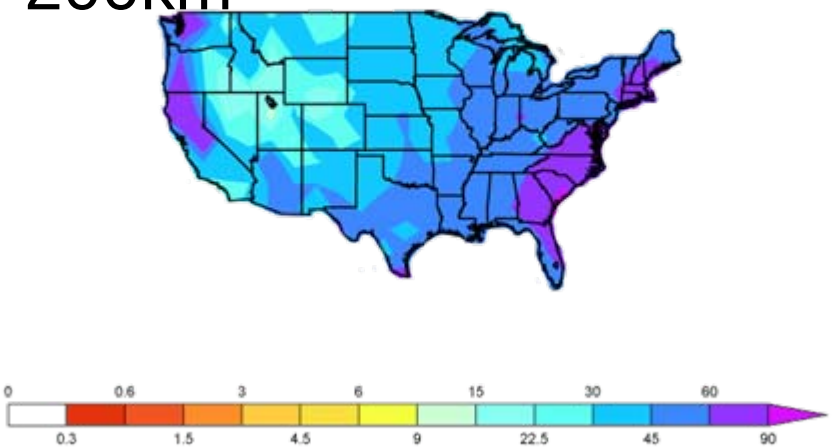


Global fossil fuel CO_2 emissions with division into portions that remain airborne or are soaked up by the ocean and land.

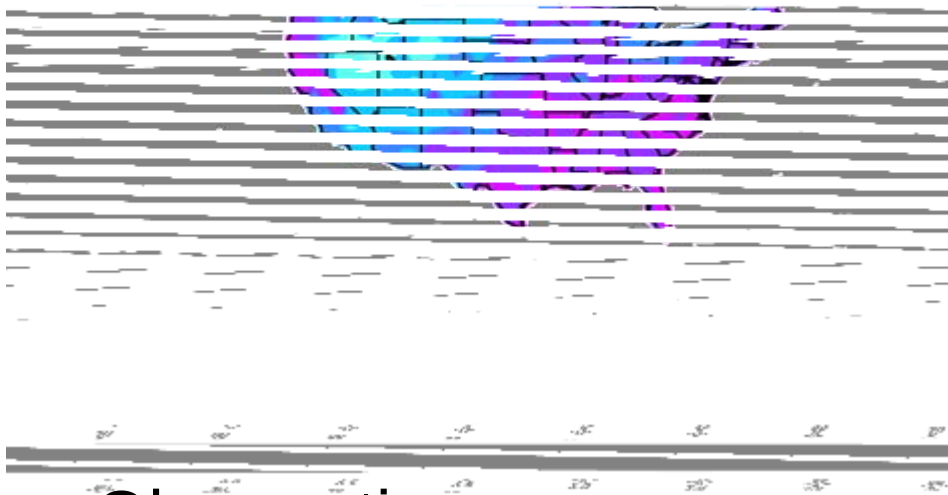
Source: Hansen and Sato, *PNAS*, **101**, 16109, 2004.

Higher resolution for precipitation* fidelity

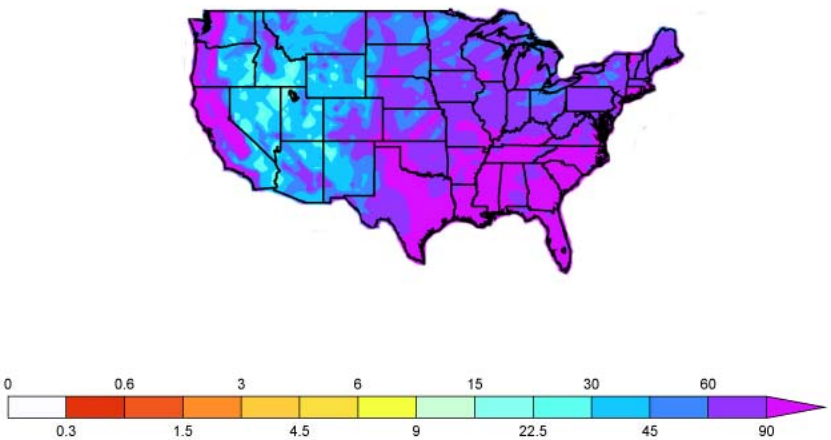
200km



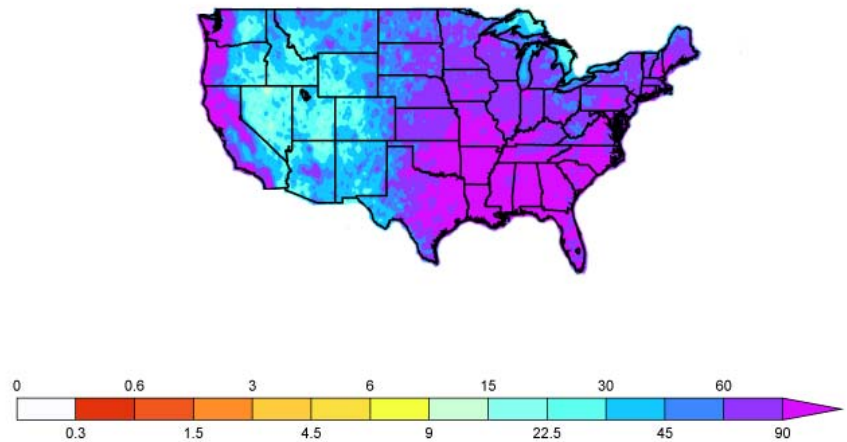
100km



50km

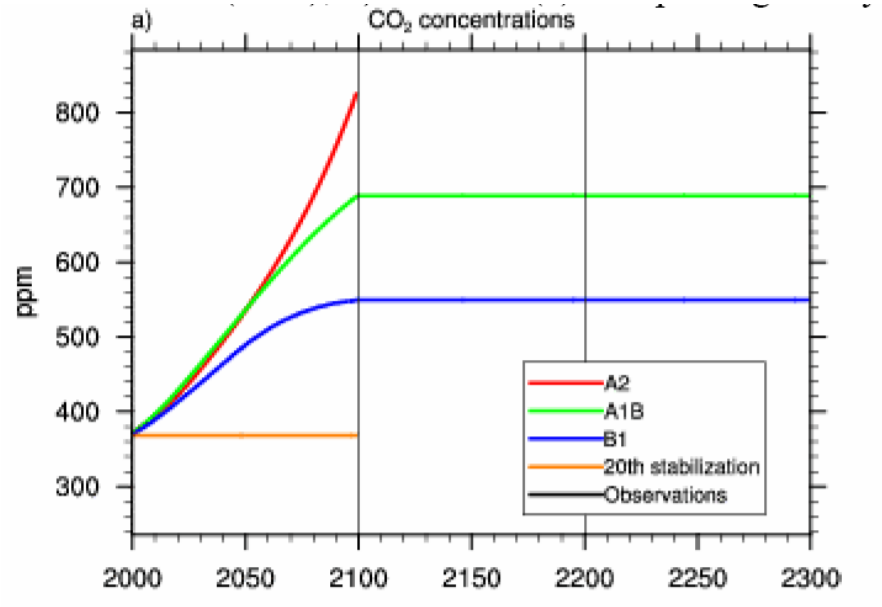


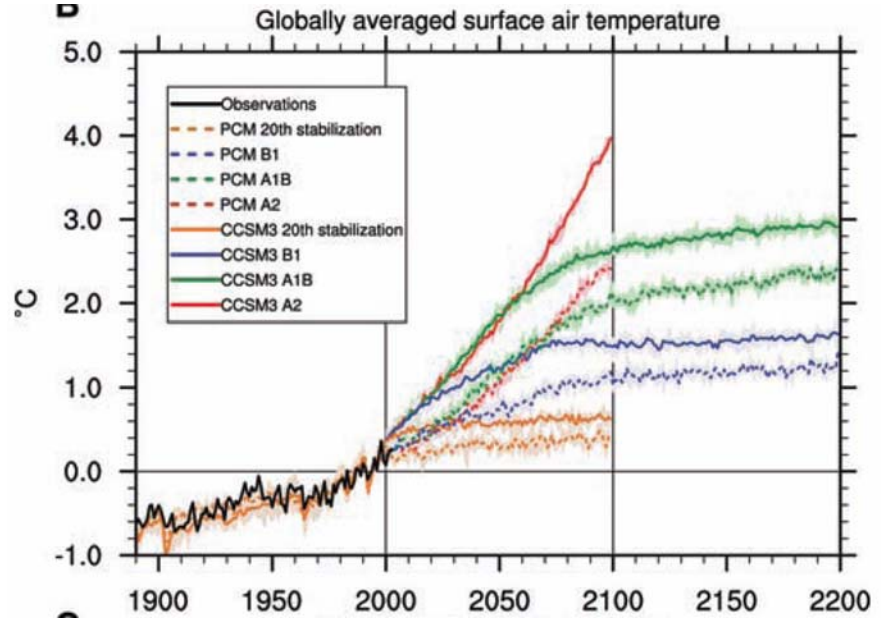
Observations



*20 year annual maximum daily precipitation return value

Convergence of near-term climate forecasts

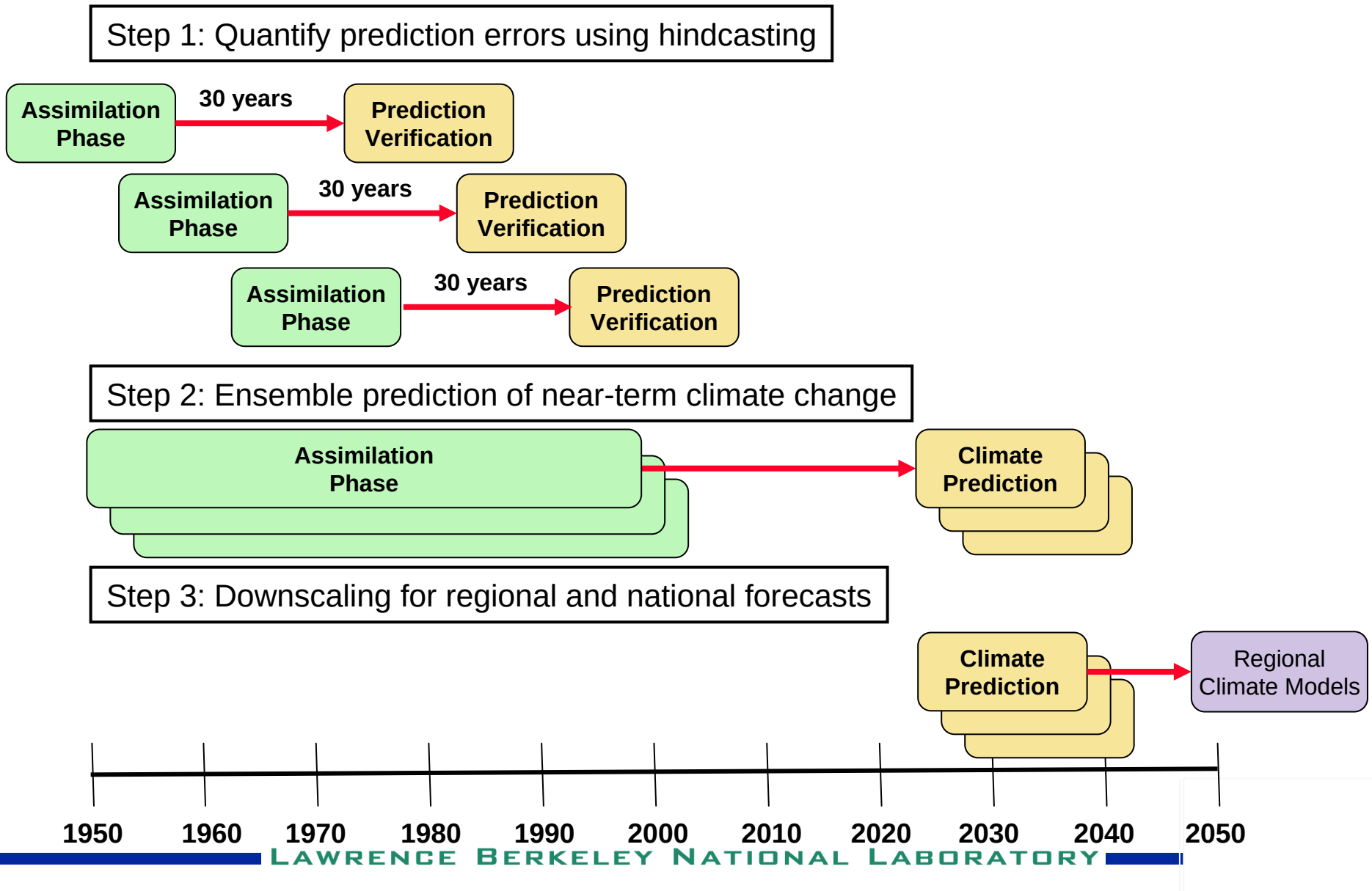




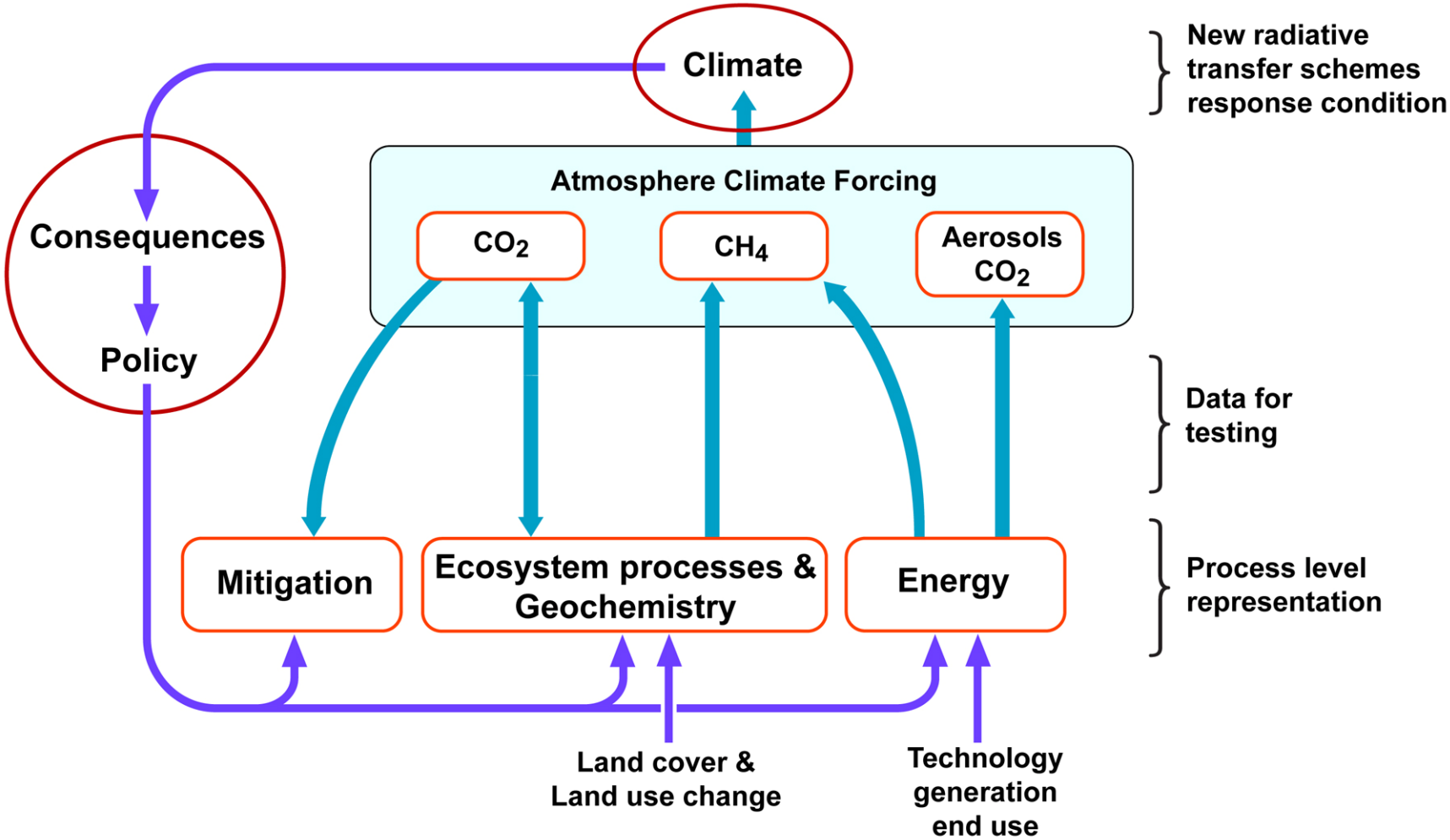
Meehl et al, 2005

- Between 50 to 70% of warming in 2050 relative to pre-industrial periods Is “committed”.
- Therefore the short-range predictions are relatively insensitive to socioeconomic scenarios.

Schema for short-range prediction



Coupled Earth system / policy models



Conclusions

- Recent climate change is very likely human-induced.
- Near-term climate change before 2030:
  - *Western US will be noticeably warmer compared to climatology.*
  - *Predictions converge across models and scenarios.*
  - *This convergence could facilitate process of adaptation.*
- Long-term climate change by 2100:
  - *Extremes include less frost, more dry spells, longer heat waves.*
  - *Warming increases with increasing levels of atmospheric CO_2.*
- There are real prospects for more dynamic coupling of climate modeling, impacts, adaptation, and mitigation.